The ecology of the American badger *Taxidea taxus* in California: assessing conservation needs on multiple scales.

By

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B.S. (University of California, Santa Barbara) 1998
M.S. (University of California, Davis) 2004

DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Ecology

in the

OFFICE OF GRADUATE STUDIES

of the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:

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2008

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Ann Arbor, MI 48106-1346

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ACKNOWLEDGEMENTS

Funding and support for this research was generously provided by the California Department of Fish and Game/UC Davis Wildlife Health Center Resource Assessment Program; the American Wildlife Research Foundation; the American Society of Mammalogists; the American Museum of Natural History's Theodore Roosevelt Memorial Grant Program; the Western Section of the Wildlife Society; the Chuck Haugen Conservation Foundation; UC Davis Jastro-Shields Graduate Research Grants; and Block Grant Fellowships from the UC Davis Ecology Graduate Group.

I wish to express my sincerest gratitude to my advisor, Rosie Woodroffe, for musing during our first meeting together, "Hmm…what about badgers?" Her incredible enthusiasm for carnivores, and her complete confidence in my abilities were instrumental in my undertaking and completing this project. Rosie also provided insightful mentorship and advice when I was particularly challenged by the rigors of solely managing a large project. I feel very lucky to have had the opportunity to learn from such an accomplished and passionate conservation researcher.

Special thanks to Mark Schwartz, for serving on my orals committee and dissertation committee. Mark truly went above and beyond—supporting my independent study of landscape ecology, brainstorming analysis ideas for a somewhat problematic dataset, and even stepping in to escort me through graduation ceremonies. I am impressed by and grateful for Mark's unwavering commitment to the students of the Graduate Group in Ecology. Thanks too to Steve Greco, who also served on my orals and dissertation committee. Steve selflessly devoted his complete attention to our sometimes multi-hour meetings; and his enthusiasm for conservation in California,

particularly in the Central Valley, was infectious. I have been so inspired by his ability to address land-use management issues with his research. I would also like to thank Dirk Van Vuren for his assistance as I stumbled through the administrative aspects of my project, and for sharing badger stories of his own with me. My lab-mates, Hilary Swarts, Rachel Mazur, Matt Swarner, and Katie Prager helped me maintain my sense of humor.

Christine Kreuder-Johnson, Steve Torres, and Eric Loft were instrumental in developing this project. Collaborating with Chris and Kirsten Gilardi was a wonderful experience; it is rare to find as energetic, collaborative and productive a team as exists at the Wildlife Health Center! My sincere thanks also to Mike Murray, Dave Jessup, Amy Wells, Sue Campbell, everyone at Avian and Exotics Veterinary Clinic, and all the staff at the Marine Wildlife Veterinary Care and Research Center in Santa Cruz for being at beck and call for badger surgeries. Thanks too to Dale Steele and Esther Burkett at CDFG for assistance with the Species Status Report.

I feel so lucky to have encountered the amazing group of people in Shannon Bros's lab at San Jose State University, particularly when I was feeling somewhat isolated in my trailer in the wilds. Thanks so much to Shannon for offering guidance, advice, insight, and friendship from the moment I met her. Chris Lay truly laid the foundation for what became my dissertation, and all badger researchers in California that follow should be grateful for his pioneering work in field. I also enjoyed getting to know Chrissie Klinkowski, Leslee Parr, and Mary Poffenroth both professionally and unprofessionally! Thanks to Rick Hopkins for advice along the way. Finally, very special thanks to my colleague and collaborator, Tanya Diamond. Tanya's unfailing optimism and assistance truly carried me through much of this project. It has been such a privilege to have found such an incredible fellow badger researcher, and I'm glad to have had the opportunity to take this journey together.

Bruce Delgado is truly a force of nature. Without his advocacy and assistance, this project would never have been possible. I thank him for introducing me to the Fort Ord community, and for his continued excitement about badgers and conservation. The members of the BLM Fort Ord Field Station graciously hosted my stay in their backyard, and made me feel so welcomed. Dairen Simpson has forgotten more than I will ever know about trapping. I am honored to have had the opportunity to glean even the smallest amount of his knowledge. I look forward to the next time we work together in the field, and hope he can manage to be at least a little bit funny this time.

Thanks to all my assistants and interns: Geriann Albers, John Clare, Johanna Davis, Bruce Delgado, Tanya Diamond, Jessica Dunlap, Mark Elbroch, Janel Fishpaw, Tim Fullman, Jessica Gist, Kimberley Greeson, Andrew Hida, Colin Hoisington, Daniel Jackson, Tammy Jakl, Marina Kasa, Courtney McSherry, Vivian Nelson, Mary Paul, Patt Quinn-Davis, Alyssa Stark, Patrick Switzer, Nicole Tautfest, Brett Williams, Topo, and the BLM Fort Ord Field Station Volunteers. They were absolutely amazing. I could never have done any of this without them. Many agencies allowed me on their land to scout for badgers, for which I am also sincerely grateful: BLM Hollister Office (Fort Ord Field Station), Sierra Foothills Conservancy, Sequoia Riverlands Trust, Sacramento Valley Conservancy, Pacheco State Park, BLM Carrizo Plain Natl. Monument, US Army National Guard Camp Roberts, City of San Luis Obispo, NPS Point Reyes National Seashore, Big Sur Land Trust, the Las Palmas Development, and the UC Natural Reserve System.

Finally, my love and thanks to my family and friends for supporting me through this long journey. My friends were endlessly tolerant of my somewhat flaky tendencies, and never failed to keep me humble. I am especially indebted to my wonderful friends at Zuda, for helping me find a way to balance it all and to truly be happy while doing it! The amazing family that raised me: Mom and Dad, Kate, Mary Jo, Tommy and Julie, Lou, Connie, Julie and Pete, Jack and Dorothy, Kathy and Chip...each and every one of them played a role in creating the person I've become. Thanks to my parents who have always encouraged and trusted me. Their support has allowed me to live this adventure. Thanks and love to my sister Jo, who will someday go backpacking with me, and to all of the rest of my family.

I am especially grateful to Brett, for just about everything. He encourages and inspires me in just about every way that makes me a better person. And honestly, there is simply no one more fun to hang out with. Except perhaps Topo. Thanks, Topo.

I would like to dedicate this dissertation to my mom, who taught me by her example. I hope I can be the same inspiration for little what's-her-name.

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Abstract

Regional conservation planning is often guided by the use of focal species, whose persistence can serve as a measure of the habitat elements to be maintained or enhanced by conservation action. Here, I investigated the ecology of the American badger (*Taxidea taxus*) as a focal species for regional conservation planning in California. First, I investigated home range size and habitat use of nine radio-implanted badgers. At the study site scale, home ranges were sited in grasslands, sandy/loamy soil types, and close to recreational trails. Within their home range, badgers showed only a preference for intermediate slopes over very steep slopes. Dens within badgers' home range were associated with native grassland and scrub habitat, showed an avoidance of flat slopes, and tended to be found within 500 meters of trails. Second, I examined the fine-scale movement patterns of American badgers. Travel speeds were greater during the mating season and spring than they were in the winter for both sexes. Vegetation type affected the travel speed of males during the fall and spring; however, travel speed during the mating season was not affected by vegetation type. Finally, I used occurrence data to identify landscape factors affecting the population distribution of American badgers in California, and to examine the factors associated with declines in badger occurrences over time. Environmental features associated with badger occurrences and declines varied by ecoregion: an association with grassland and shrub cover was detected in some ecoregions, while an association with forest and woodland habitat was detected in others. In remote ecoregions, human-altered habitats were positively associated with badger occurrences. Declines in badger occurrences were associated with human-altered landscapes in two ecoregions. These results will inform conservation planning by

identifying 1.) area requirements for badgers, 2.) characteristics of habitat necessary for their behavioral activities, and 3.) factors that may affect corridor efficacy in badger habitat. Results also establish the geographic extent to which badgers should be considered in regional conservation plans, and identify habitat factors specific to each ecoregion that may affect badger persistence and thus their role as a focal species.

INTRODUCTION

Conservation in the past has focused primarily on the establishment of protected areas; however, only recently has it become apparent that these areas can be insufficient in conserving some large scale ecosystem processes. Particularly, wide-ranging species almost always use or move through habitat outside reserve borders, often suffering high mortality rates and affecting population persistence within protected areas (Woodroffe and Ginsberg 1998). Thus, the characteristics of the landscape in between and surrounding protected areas can often be an important determinant of whether or not a wide-ranging species can survive in a fragmented landscape (Sisk *et al.* 1997, Ricketts 2001, Brotons *et al.* 2003, Selonen & Hanski 2003). A level of protection that includes even the most wide-ranging, sensitive species brings us closer to our goal of conserving intact systems, as well as intact guilds of species associated with habitats or ecoregions.

The state of California has made great strides towards a more regional approach to conservation planning in recent years, with the goal of maintaining large-scale processes and the needs of wide-ranging species. Regional conservation plans, such as Habitat Conservation Plans (HCPs), Natural Community Conservation Plans (NCCPs), and several non-profit regional planning efforts (i.e. the South Coast Wildlands Project, the Conception Coast Project), focus on connecting existing protected areas through the acquisition and incorporation of land between them. Areas of compatible human use can also serve as habitat and be integrated into the reserve network. Determination of the arrangement of reserve networks depends on estimated measures of connectivity. Connectivity is not necessarily an attribute of a landscape that can be objectively estimated. It is a function of that landscape—it must allow movement of the species of concern. Wide-ranging carnivores are often used to help design regional conservation plans (Noss *et al.* 1996, Berger 1997, Lambek 1997). Due to their low population densities, large range sizes, and vulnerability to extinction (Crooks 2002, Woodroffe and Ginsberg 2000), carnivores provide a sensitive measure of the both the scale and degree of connectivity required for a regional conservation action (Crooks 2002, Virgós *et al.* 2002, Ray 2005).

If a species is to be used to assess connectivity (a "focal species," Lambek 1997), a thorough understanding of its behavior in fragmented habitat is essential (Caro 1998, Tischendorf & Fahrig 2000). Many studies have focused on the effects of patch size, isolation and quality (Crooks 2002, Virgós *et al.* 2002, Fleishman *et al.* 2002, Krawchuk & Taylor 2003) on population sizes or species occurrence. However, we know relatively little about how animals disperse through or use fragmented habitat. For wide-ranging species, movement behavior, mortality, and the habitat use in the "matrix" that must be used or crossed between habitat patches can have a strong effect on population distribution and persistence (Boudjemadi *et al.* 1999, Ricketts 2001, Selonen & Hanski 2003). Fragmentation can restrict these populations two ways. First, an animal can be restricted to intact habitat, rendering it unable to cross a matrix and colonize distant patches. Alternatively, an animal may use matrix habitat (Brooker *et al.* 1999, Care 2002), but may incur reduced breeding success or increased mortality rates compared to contiguous habitat (Purcell & Verner 1998, Misenhelter & Rotenberry 2000, Pidgeon *et al.* 2003). Finally, the extent to which an animal uses matrix habitat may be variable, depending on the animal's activity (i.e. foraging vs. dispersing) and season (i.e. breeding vs. non-breeding). Data that address species occurrence patterns without addressing behavior are insufficient in explaining the mechanisms that achieve connectivity, and thus have a limited ability to predict how fragmentation will affect populations (Johnson *et al.* 1997, Tiebout & Anderson 1997, Collinge 2000, Crooks 2002, Gehring & Swihart 2003). Understanding these mechanisms provide a clearer picture of the effect of habitat fragmentation on wide-ranging species, and is crucial to ensuring the success of conservation plans in maintaining their populations.

In using a focal species for conservation planning, assessments of that species' ecology and distribution should optimally occur at more than one scale. One reason is that the effects of habitat factors on behavior at the small scale can ultimately affect population distributions on the large scale. Thus, local species extirpations may eventually lead to large-scale range contractions. Secondly, the presence of that species within the planning area, both historically and recently, should further determine the appropriate role the focal species should play in the planning process. Factors associated with the species' presence and persistence across several time periods may vary regionally, thus requiring the specific use of that focal species be tailored to a distinct geographic region. For many species, the best available data on population distribution is sightings or trapping data. These data can be appropriate for assessments at the large scale (Stoms *et al.* 1993), for constructing coarse habitat models (Palma *et al.* 1996, Carroll *et al.* 2001, Livatis *et al.* 2006), or to make comparisons of species' range extents across several time periods (Rodriguez & Delibes 2002, Rodriguez & Delibes 2003).

The research undertaken here addressed regional conservation planning in the rapidly urbanizing landscape of California. The proliferation of regional plans—37 regional or subregional HCPs and NCCPs alone over the past 10 years—is a testament to their promise as a land management tool. Several carnivores have served as focal species in chaparral and forest habitats (Crooks 2002, Beier 1994, Carroll & Noss 1998). However, there is a need to expand this approach significantly. First, regional planning for grasslands has lagged behind that for other habitats. In California, while this habitat is considered among the highest priority for conservation, it is also the least protected—less than 10% of grasslands enjoy at least moderate levels of protection from development (Davis *et al.* 1998, Olsen & Cox 1999). Second, it is imperative that a wide-ranging grassland carnivore be used as a focal species in developing these plans and assessing landscape connectivity. Such an assessment should be grounded not only in an understanding of the spatial behavior of individual animals, but also on known large scale patterns of species occurrence. Thus far, the only terrestrial carnivore considered as a focal species in grasslands is the San Joaquin kit fox (Gerrard *et al.* 2001); however, due to its extremely narrow range, its utility as a focal species statewide may be limited.

The American badger (*Taxidea taxus*) is a highly specialized, semi-fossorial mustelid of open prairies and oak woodlands. While populations appear to be stable or increasing in most areas east of the Rockies, badger populations on the west coast are of a more uncertain status. In British Columbia, for example, the remnant population of an estimated 300 animals is considered critically endangered (Hoodicoff 2003). In California, Department of Fish and Game (CDFG) surveys suggested that the range of the badger had contracted significantly between the 1930s and 1980s. Populations were thought to be extirpated throughout the western foothills of the Sierra Nevada, the inland grasslands of the Central Valley, and the northern coastal grasslands (Larsen 1987).

These findings resulted in the listing of the badger as a Species of Special Concern by CDFG.

Badgers can have incredibly large range sizes for their body size-- up to 200 km^2 for a 15 kg individual (Apps *et al.* 2002, Hoodicoff 2003). Even when home range sizes are small (2 km^2), dispersal distances can still be over 200 km (Messick & Hornocker 1981). Compared with other carnivore species, badgers may be extremely sensitive to habitat fragmentation, persisting only in contiguous habitat blocks (Crooks 2002, C. Lay *unpublished data*, J. Quinn *unpublished data*). A recent study of carnivores in southern California habitat fragments found badgers only in the largest of the fragments surveyed—much larger than that would be predicted by their body size (Crooks 2002). A few regional conservation plans in California have listed the badger among the potential focal species, but lack the data—regarding behavioral ecology or even general occurrence—to inform conservation action (California Wilderness Coalition 2001, Luke *et al.* 2004). Indeed, despite potential conservation concerns, almost nothing is known of badger ecology in California; more widely, there have been very few ecological studies carried out on the species. None of these have occurred in California, and none have been undertaken in a fragmented, urbanizing landscape. Further, no statewide monitoring or assessment of badger populations in California has occurred since listing in 1986.

The dissertation that follows is a result of work conducted under a CDFG/University of California, Davis Wildlife Health Center (WHC) Resource Assessment Grant. The Resource Assessment Program (RAP) was formed to support scientific and applied research related to the habitat and community needs of wildlife at risk in California. Projects were funded that specifically addressed the distribution, habitat requirements, dispersal patterns, seasonal movements, population trends, and factors affecting the health and survival of vertebrate wildlife species. Species listed as Threatened, Endangered, or of Special Concern were considered a priority for research. Focusing on the American badger, in Chapter 1, I analyzed the spatial behavior and habitat preferences of a population of badgers in Monterey County, California. The data collected were aimed at providing better guidelines for area requirements for badgers, as well as determining the characteristics of habitat necessary for behavioral activities such as denning and foraging. In Chapter 2, I investigated factors influencing the fine-scale movement behavior of badgers; specifically whether habitat selectivity dictated movement paths, and whether this varied by season or gender. Individual movement patterns can reveal an animal's propensity to use habitat corridors between protected areas, and can also be used to understand the structural (i.e. habitat), temporal (i.e. season), and demographic (i.e. gender) factors that may render a corridor effective or ineffective for maintaining connectivity. Finally, in Chapter 3 I addressed factors associated with badger occurrence and declines of occurrence throughout California. Results from this analysis were intended to establish the geographic extent to which badgers should be considered in regional conservation plans, and to identify habitat factors specific to each ecoregion that may affect badger persistence, and thus their role as a focal species.

Background

Biology

The American badger (*Taxidea taxus*) is one of nine species of badgers worldwide, all of which are classified in the family Mustelidae (which also contains weasels, skunks and otters). Four subspecies of *T. taxidea* are recognized; *T. t. berlandeiri*, *T. t. jacksoni*, *T. t. jeffersonii*, and *T. t. taxus*; all of which differ in size and pelage color. Two of these subspecies are reported to occur in California: the paler and smaller *T. t. berlandeiri* in the inland southern deserts, and the larger and darker *T. t. jeffersonii* in the coastal areas, Sierra Nevada range, and Great Basin. Specimens from the Central Valley have been assigned to both *T. t. berlandeiri* and *T. t. jeffersonii*. Long (1973) classified the entire population in that area as *T. t. berlandeiri* while noting that some intergradations between the two subspecies were possible based on the intermediate characteristics of some of the specimens. Williams (1986); however, suggested the classification of the Central Valley population as *T. t. jeffersonii* is more warranted due to the higher number of *T. t. jeffersonii* specimens collected there.

American badgers are uniquely adapted to maintain a semi-fossorial lifestyle. Although their eyesight is poor, their auditory and olfactory senses are acute (Long 1973). Their broad, powerful chest, large front legs, and long claws make them efficient diggers; while their wedge-shaped head allows them to tunnel into burrows after prey. Badgers have been observed digging themselves out of sight in less than 2 minutes in hard-packed soil (Grinnell *et al.* 1937). Their hide is thick and loose on the body; enabling badgers to turn around in small spaces, and a nictating membrane protects the eye from flying soil. When not digging, badgers move low across the ground; because of their long fur and short legs, they often appear to glide (although they occasionally lope as well). Badgers will also push themselves up high on their front legs or even sit on their hind legs to scan the landscape and sniff the air. They also quite often bask on the tailing of soil in front of the burrow entrance. Pursuit of a badger will typically end at a badger burrow, and many sighting of badgers are of the animal's head sticking up out of the burrow entrance before quickly disappearing below ground.

Badgers are primarily carnivorous, and their diet reflects an ability to exploit a wide range of food types. Small mammals typically comprise most of the diet, particularly ground squirrels (*Spermophillus sp.*), voles (*Microtis sp.*), mice (*Peromyscus sp.*), gophers (*Geomys sp.*), rabbits (*Slyvilagus sp.*, *Lepus sp.*), marmots (*Marmota sp.*) and prairie dogs (*Cynomys sp.*). Birds and bird eggs are also taken, as well as reptiles, amphibians, insects, and occasionally even fish. Badgers have also been reported to dig up wasp nests and to scavenge large game (Errington 1937, Snead & Hendrickson 1942, Jense 1968, Sargeant & Warner 1972, Hart & Trumbo 1984, Goodrich & Buskirk 1998, Sovada *et al.* 1999, Newhouse & Kinley 2000, Armitage 2004). The frequency of each type of food item in a badger's diet over the course of the year often depends on its availability, suggesting that badgers are opportunistic in their foraging habits (Jense 1968, Sovada *et al.* 1999). In California, badger digs are often found in association with California ground squirrel (*Spermophillus beecheyi*) colonies in the Diablo and Gavilon ranges, the Coast ranges, the Sierra Nevada foothills, and in the southern San Joaquin valley; and ground squirrel remains have been found near active badger mounds in these areas. In the Central coast, pocket gopher (*Thomomys bottae*) remains were often found in badger mounds; and the activity of radio-marked badgers in Monterey county was concentrated in areas of high levels of gopher and meadow vole (*Microtis californicus*) activity. In the same study, badgers were also observed to dig up wasp nests, predate a quail nest, and raze wood rat (*Neotoma fuscipes*) lodges. The remains of lizards (sp. unknown) were also found in these badger mounds. Badgers in the central coast study were not; however, observed to dig in the few ground squirrel colonies within their home ranges (Quinn *unpublished data*, Diamond *unpublished data*). Grinnell *et al.* (1937) reported similar prey preferences, and also noted that kangaroo rats seemed to be the dominant prey item in the southern San Joaquin Valley, Douglas ground squirrels in the upper Sacramento Valley, and Townsend's ground squirrel was important in the Owens Valley. He also cited observations of badgers consuming rattlesnakes, bumblebee nests, and Jerusalem crickets.

A polygamous species, badgers mate in the late summer and early fall. Male badgers begin seeking receptive females as early as July (Minta 1990), expanding their home ranges as much as 2 to 3 times their non-breeding season size to locate as many females as possible (Minta 1993, Goodrich & Buskirk 1998). Mating occurs July through September (Hamlett 1935, Minta & Marsh 1988). Competition between males for females can occur in some populations. In one instance, copulation between one pair of badgers took was observed in the daytime, and lasted 21 minutes. During this time, a third reproductive male tried to disrupt the mating pair, and was chased by the female and attacked by the mating male when copulation was complete (Campbell & Clark 1983). Minta (1993) observed scarring on 73% of captured males (n = 52) in a Wyoming study. Such scars and wounds were presumed to be from conflicts over females in a population where competition for females was probably intense due to a highly skewed sex ratio (1 female: 1.7 males). Breeding success may increase with age for males (Minta 1993). Thus, again, these older animals may be the primary contributors to population growth.

Although American badgers are solitary animals, home ranges of individuals often overlap between pairs of males, pairs and females, and between male-female pairs. However, the extent of home range overlap can be greater for male pairs and male-female pairs than female pairs (Minta 1993, Goodrich & Buskirk 1998). Females with overlapping ranges have been observed avoid each other temporally; however, males attract each other (Minta 1993). Such temporal and spatial attraction between solitary males may be a result of their following each other in order to locate females when they are a limited resource (Minta 1993). The spatial arrangement of badger home ranges may be maintained through chemical communication between animals. Badgers have well-developed scent glands, and have been observed dragging them on their mounds, a potential scent-marking behavior (Hornocker *et al.* 1984, Lampe *personal observation*, Quinn *personal observation*).

Badger home ranges as reported in the literature are range from 1.6 – 65 km^2 for females and 2.4 – 541 km^2 for males (Table 1). The variation in home range size between these studies likely reflects variation in resource availability between the study sites. As with many species, badgers utilizing resources that are temporally or spatially dispersed may tend to have larger home ranges. In British Columbia, for example, at the northern extent of their range, badgers prey primarily on Columbian ground squirrels, which are an extremely patchy resource. Thus home range sizes in British Columbia, as expected, are among the largest (Newhouse & Kinley 2000, Hoodicoff 2003). In the Santa Monica Mountains, California, badger home ranges for two female badgers tracked during the month of July were 1.4 and 3.7 km^2 (Lupis *et al.* 1999). Given that these home range sizes reflect only one month of tracking, seasonal and annual home ranges were likely to be significantly larger. Daily movement patterns of badgers are also varied. On average, badgers move about 0.5 km in a night (Lindzey 1978, Collins 2003, Hoodicoff 2003); however, movements of 14 km in 4 hours have been recorded (Hoodicoff 2003). One badger in Minnesota completed a circuit of 17 miles over the course of 2 weeks (Sargeant & Warner 1972). Badger movements in Texas were slightly less (Collins 2003).

Distribution and Abundance

Because badgers are nocturnal, semi-fossorial, not always easily recognizable, and have never been formerly monitored, the many gaps in knowledge of the geographical range of the badger within California have been filled with the assumption that they are present nearly everywhere. Indeed, to some extent, badgers probably do have the potential to occur sporadically almost anywhere due to their movement habits. At the same time, on the local scale, badger occurrence is easily overlooked. Traditional means of monitoring carnivores may not detect badgers as readily as would dedicated searches for their burrows, which are not often conducted.

Badgers potentially occur throughout the entire state of California, except perhaps for the far northwestern corner, and at all elevations up to 13,000 feet. In the mid-1800s through early 1900s, the centers of abundance were in the valleys and hills of the Coast ranges, in the uncultivated rolling hills and margins of the Great Valley, on the Great Basin Plateau, and in high mountain meadows and plateaus of the Sierra (Grinnell *et al.*

1937). The distribution of known badger occurrences throughout the state generally reflects this pattern. However, large-scale land conversion, such as agricultural development in the Central Valley is likely to limit the ability of badgers to truly have a continuous range throughout the state. It is not known to what extent geographical features or human-modified landscapes function as barriers between clusters of sightings.

The widespread geographical range of the badger may tend to obscure whether or not population densities are stable, increasing, or decreasing. Badgers are referred to in historical literature as "common" where they occurred (Grinnell *et al.* 1937). No quantitative data supports or rejects this assertion. Trapping records remain the only indication of badger numbers historically, and even these are biased due to variations in trapping effort dictated by pelt prices. For example, Grinnell *et al.* (1937) suggest that the value of badger pelts was minimal until around 1927, when demand for long badger fur suddenly spiked. Trapping badgers became much more profitable at this time, resulting in greater numbers of animals taken. Numbers of badgers were thought to have been significantly reduced throughout their range during this period, except for perhaps in the hills near the Great Valley (Grinnell *et al.* 1937). Pelt prices—and thus demand for badgers—again spiked in the late 1970's, when almost 300 badgers were reported trapped in one year (Williams 1986). Although data between the late 1970's and late 1980's were not examined for this report, trapping records in the late 1980's suggest that badgers were still being trapped in high numbers. Unfortunately, these trapping data exclude the number of badgers trapped or killed for non-commercial or non-recreational purposes. No permit or formal reporting is required for badgers killed due to depredation. Numbers taken in recent years suggest that this quantity is considerable (discussed below), and thus may have been in historical times as well.

Reported permitted trapping take for badgers has declined significantly in recent years; however, this is likely due in large part to a decline in pelt prices—as well as an overall decline in trapping permits sold—rather than solely due to declines in actual badger numbers. Trapping take for depredation is not recorded, but may occur in much higher numbers. In a 2004 hunter's survey, 34 hunters reported taking a total of 168 badgers from Siskiyou County for depredation in 2003-2004 (Lauridson 2005). Similarly, Wildlife Services continue to take high numbers from Siskiyou County as pest control, although these numbers too have declined in recent years. Again, the extent to which these numbers represent badger population size is not known.

Badger abundance or population size in California is difficult to estimate. Population density of badgers likely depends on resource abundance and distribution, which varies considerably across the state. In other states, badgers live at densities ranging from 5 animals per square kilometer to 0.17 animals per square kilometer (1 animal per 6 km^2) (Lindzey 1971, Messick & Hornocker 1981, Minta & Mangel 1989, Goodrich & Buskirk 1998, Ramey & Bourassa 2005). These densities are estimated and may not reflect true badger densities in those areas; however, such estimates are potentially useful as relative indices of abundance. In California, badger density was estimated to be at minimum 0.25 animals per km^2, or 1 badger per 4 km^2 in the Fort Ord Public Lands. If this population density correlates with the density of digging activity (new badger holes/km^2), then badger densities in other parts of the state are much lower based on the digging activity observed in those locales. Population estimates as reported to USDA-APHIS by CDFG range from 96,362-1,252,705 animals. However, under the most generous estimates—such as if badger densities estimated at Fort Ord existed in all of the most suitable habitat in California—then the statewide population would be 72,500 animals. As badger sightings are 1.) rarely reported outside the most suitable habitat on the statewide scale, and because 2.) several large areas of suitable habitat contain no sightings, and 3.) suitable habitat were badger activity has been indexed may contain lower population densities than that of Fort Ord; an estimate of 72,500 should be considered an absolute maximum. Realistically, it seems that the true population size would be far less than that. Taking the average index of badger activity in all the sites surveyed (4.42 digs/km^2) and scaling that number to the activity index from a population of 1 badger per 4 km^2 (14.10 digs/ km^2/0.25 badgers/ km^2) would result in a statewide population size of 22,400 animals, if all suitable habitat was occupied. However, as badger digging activity has not been definitively shown to correlate with badger population density (Messick 1987), these numbers too are speculative.

Management

The American badger (*Taxidea taxus*) was listed as a species of special concern on February 26, 1986 as part of an effort by California Department of Fish and Game (CDFG) to identify taxa in California that lacked a listing status of Threatened, Endangered, or Fully Protected, yet still seemed vulnerable to extinction (Williams 1986). Data used to assess the conservation priority of the 52 species considered in that effort were gathered through literature reviews, museum specimens, consultation with experts, and some field studies of varying detail. Efforts were made to use as current data as possible (until 1985), and based on the findings, each species on the resulting List of Concern was assigned to one of three classes of conservation priority:

- Highest priority—(high probability of extinction if current trends continue)
- Second priority—(definitely declining in population size and appear jeopardized, but the threats are less immediate)
- Third priority—(do not appear to face extinction soon, but populations are declining seriously or are otherwise highly vulnerable to human developments) (Williams 1986).

Badger populations were recognized to have diminished in large parts of their range prior to the 1930's, although specific population data were admittedly lacking. They were classified as "Third priority." Recommendations for future conservation actions included population monitoring, particularly in the western lowlands of California; assessment of impacts of habitat loss, rodenticide use, and trapping on populations; mandatory reporting of take by licensed trappers; and determination of home range and prey requirements (Williams 1986). As a follow-up to the badger's inclusion on the List of Concern, CDFG conducted a population distribution study in 1987. Occurrence data for the 1987 study were garnered through surveys mailed to licensed trappers, animal control officials, and agency personnel throughout the state. The 521 responses received contained mostly reports from the 1970's to 1980's. Historic data were then compiled from trapping reports summarized by Grinnell *et al.* (1937). Qualitative comparison between the two survey periods suggested that badgers had disappeared from parts of their historic range in California, particularly from the Central Valley and Northern coast. Populations appeared to persist elsewhere throughout the state. A list of 4 recommendations resulted from these findings: that badgers retain their listing status as a species of special concern; that similar surveys be conducted every 10-15 years to establish population trends; that formal census methods be developed and employed in future monitoring; and that in the Central Valley and Northern coast areas, lethal control of badgers in be replaced with relocation and use of rodenticide be minimized (Larsen 1987). No further assessments by CDFG were completed.

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CHAPTER 1

ACTIVITY-SPECIFIC HABITAT PREFERENCES OF BADGERS (*TAXIDEA TAXUS*) IN COASTAL CALIFORNIA

Abstract

Mapping the availability of suitable habitat for species often serves as a foundation for developing conservation plans. In many species, different habitats may be used for different activities, which should also factor into conservation planning efforts. In this study, I investigated home range size and habitat use in the American badger (*Taxidea taxus*), a semi-fossorial grassland carnivore. Nine radio-implanted badgers, 5 females and 4 males, were tracked for up to 18 months in Monterey County, California. Using compositional analysis, I examined whether badger preference for vegetation type, soil type, slope, or recreational trail proximity for daytime denning differed from that preferred for nocturnal foraging and traveling. Analyses were conducted at both the study site and home range scale. Badger home ranges were between 1 and 26 km^2. At the scale of the study site, home ranges tended to be sites in grasslands and in sandy/loamy soil types. Home ranges also tended to be located in close proximity to recreational trails. Within their home range, badgers showed no preference for vegetation type or soil type while active, but preferred intermediate slopes to very steep slopes. For den placement within their home range; however, badgers preferred native grassland and scrub habitat over riparian/wetland and urban areas, and preferred intermediate slopes to flat slopes. Dens also tended to be found within 500 meters of trails. Grassland conservation efforts that use badgers as a focal species should consider these different types of habitat use when determining the configuration of both core and corridor habitat, and when planning for land use within protected areas.

INTRODUCTION

Wide-ranging carnivores are often used as focal species in designing regional conservation plans (Noss *et al.* 1996, Berger 1997, Lambek 1997). Due to their low population densities, large home range sizes, and vulnerability to extinction (Crooks 2002, Woodroffe and Ginsberg 2000), the ability of a carnivore to both persist in, and move through, the landscape provides a sensitive measure of the scale and degree of connectivity required for effective conservation (Crooks 2002, Virgós *et al.* 2002, Ray *et al.* 2005). Thus, connectivity analysis (such as least-cost corridor analysis) based on the home range sizes and habitat preferences of carnivores is a widely-used tool in conservation planning (Walker & Craighead 1998).

Assessing connectivity in a landscape requires knowledge of species presence and movement patterns across broad geographic regions. However, because extensive field-based occurrence data can be lacking, species presence is often predicted based on association with certain habitat types. Many land management agencies have developed habitat models such as wildlife habitat relationship (WHR) models and habitat suitability indices (HSI), which categorize and rank habitats according to known or expected preference for each species (U.S. Fish and Wildlife Service 1981, Verner *et al.* 1986, Van Horne & Weins 1991, Brooks 1997). Since habitat maps are often readily available in geographical information system (GIS) data layers, or can be created over large areas using remotely-sensed data, habitat maps can be produced to predict species occurrences across a landscape according to habitat preferences in the models.

The accuracy of habitat-based assessments depends on whether or not a species' habitat preferences are well-characterized. Although challenging to collect, data regarding individual movement and habitat selection behavior should optimally serve as the foundation for regional extrapolations; as these behaviors often explain how larger-scale spatial factors (such as patch size and isolation, as well as characteristics of the matrix between patches) ultimately affect species presence (Boudjemadi *et al.* 1999). Additionally, in conservation planning, it is important to understand habitat selection as it is specific to animal activity patterns. For example, some species select areas with good cover for resting or denning but are able to use a mosaic of habitats for movement and foraging (Sparks *et al.*2005, Comiskey *et al.* 2002). From a planning perspective, the distinction is important when creating regional conservation plans that encompass many habitat types. It is crucial to address the function of each aspect of the habitat for the focal species being considered, such as distinguishing core/nesting habitat from corridor habitat (Comiskey *et al.* 2002).

A limitation of many WHR or HSI models is that they do not consider spatial characteristics of the habitat (Hamel *et al.* 1986, Laymon & Reid 1986, Van Horne & Wiens 1991). The mere presence of a certain preferred habitat type is generally not sufficient to support—and thus confidently predict—a species' persistence. Factors such as the size of the habitat patch, its proximity to other patches of suitable habitat, and its proximity to unsuitable habitat (such as roads, urban/suburban development, or agriculture, for example) are often critical determinants of a species' presence in a certain area (Lawler & Edwards 2002), and are driven in large part by movement behavior (Tiebout & Anderson 1997, Collinge 2000, Tischendorf & Fahrig 2000). Moreover, animals often select habitat differently on different scales (Kotliar & Weins 1990, Wu & Loucks 1995). For example, while a species may site its home range within a large forested area, it may avoid forest cover within that home range. Quite often the mechanisms that drive preference on one scale are different from those that drive preference on another. For example, dispersal ability may drive preference at the larger scale, while patterns in prey abundance and/or energetic requirements may account for preference at the home range scale (Johnson 1980, Buechner 1989, Kie *et al.* 2002, Girvetz and Greco 2007).

Here, I investigated badger movement behavior in coastal California. American badgers (*Taxidea taxus*) are increasingly being considered as a focal species for conservation planning in California grasslands. Badgers can have very large range sizes and dispersal distances for their body size-- up to 200 km^2 for a 15 kg individual (Messick & Hornocker 1981, Hoodicoff 2004). Badgers may also be more sensitive to habitat fragmentation than are other California carnivore species (Crooks 2002, C. Lay *unpublished data*). However, though listed as a Species of Special Concern in California, almost nothing is known of badger ecology in the state. More widely, there have been very few ecological studies carried out on the species. Badgers are also unique in that, despite a widespread distribution in California (Larsen 1987), they are extremely specialized in their semi-fossorial lifestyle. Not only do females dig extensive underground burrows for birthing young (Lindzey 1976), but also males and females both dig new dens almost nightly for sleeping (Long 1973, Messick & Hornocker 1981). Badgers are often found in what might appear to be marginal or ruderal habitat at the edges of intact habitat patches (e.g. agriculture, residential areas, roadsides; Apps *et al.* 2002, Hoodicoff 2003). However, in California, they do not seem to persist in fragmented habitat on a larger scale (Crooks 2002). It is possible that, in addition to the high likelihood of mortality in human-altered landscapes (Messick & Hornocker 1981), badger persistence may be limited by the availability of denning habitat in the habitat fragments that remain.

My objectives in this study were to (1) determine badger home range sizes, and (2) analyze habitat preferences at two spatial scales. At the home range scale, I also assessed habitat preference for den locations and active locations to determine whether selection patterns were different for each activity. These data will inform conservation planning efforts that currently consider badgers as a focal species.

METHODS

Study area

Research occurred in the Bureau of Land Management's (BLM) Fort Ord Public Lands in northern Monterey County, California (36.68° N 121.77° W; elevation 20-250 m). The Fort Ord Public Lands, part of a former U.S. Army base that was closed in 1994, encompass approximately 60 km^2 of grassland, coastal sage scrub, maritime chaparral, and coastal oak woodland habitats. Approximately 30 km^2 are currently managed by the BLM for recreation; and numerous biking, hiking, and equestrian trails cross the landscape. Another 32 km^2 are currently closed to all human activity as they undergo cleanup operations for unexploded ordnance by the army. The property is bounded on all sides by various types of human land uses: irrigated agriculture in the Salinas Valley to the east, low to high density residential development on the south and west, and the former army base and current California State University Monterey Bay campus (CSUMB) to the north. Fort Ord also directly abuts several roads: State Highway 68 (4 lanes) to the south, General Jim Moore Boulevard (2 lanes, residential) to the west, and Reservation Road (2 lane country road) to the east and north (Fig. 1.1).

Topography in the study site varies from relatively flat upland terraces to the northwest to steep canyons and rolling hills to the southeast. The northwestern edge of the study site experiences a strong maritime influence due to its close proximity (5 km) to the Pacific Ocean. The habitat on this side of the site is characterized by dwarfed coastal oak woodlands and maritime chaparral on sandy soils. Further away from the ocean, to the southeastern side of the study site, the vegetation transitions to extensive grasslands with areas of coastal sage scrub and oak woodland and savanna habitats. Ephemeral riparian corridors and drainages in this part of the site are dominated by willow, sycamores and oaks. Soils on the southeastern side of the site are more dominated by loams and clay composites.

The mammalian community in the site includes bobcats (*Lynx rufus*) in the oak woodlands and riparian areas, striped skunks (*Mephitis mephitis*) and coyotes (*Canis latrans*) in all habitat types, and gray fox (*Urocyon cineroargentaeus)* in the maritime. Mountain lions (*Puma concolor*), though infrequent, occurred in riparian areas and mixed chaparral. Prey species consisted primarily of gophers (*Thomomys bottae*) and voles (*Microtis californicus*) in the grasslands, kangaroo rats (*Dipodomys sp.*) in the sage scrub and chaparral, and woodrats (*Neotoma fuscipes*) in the oak woodlands. California ground squirrels (*Spermophilus beecheyi*) occurred in isolated colonies throughout the site, and were more common along the urban boundaries.

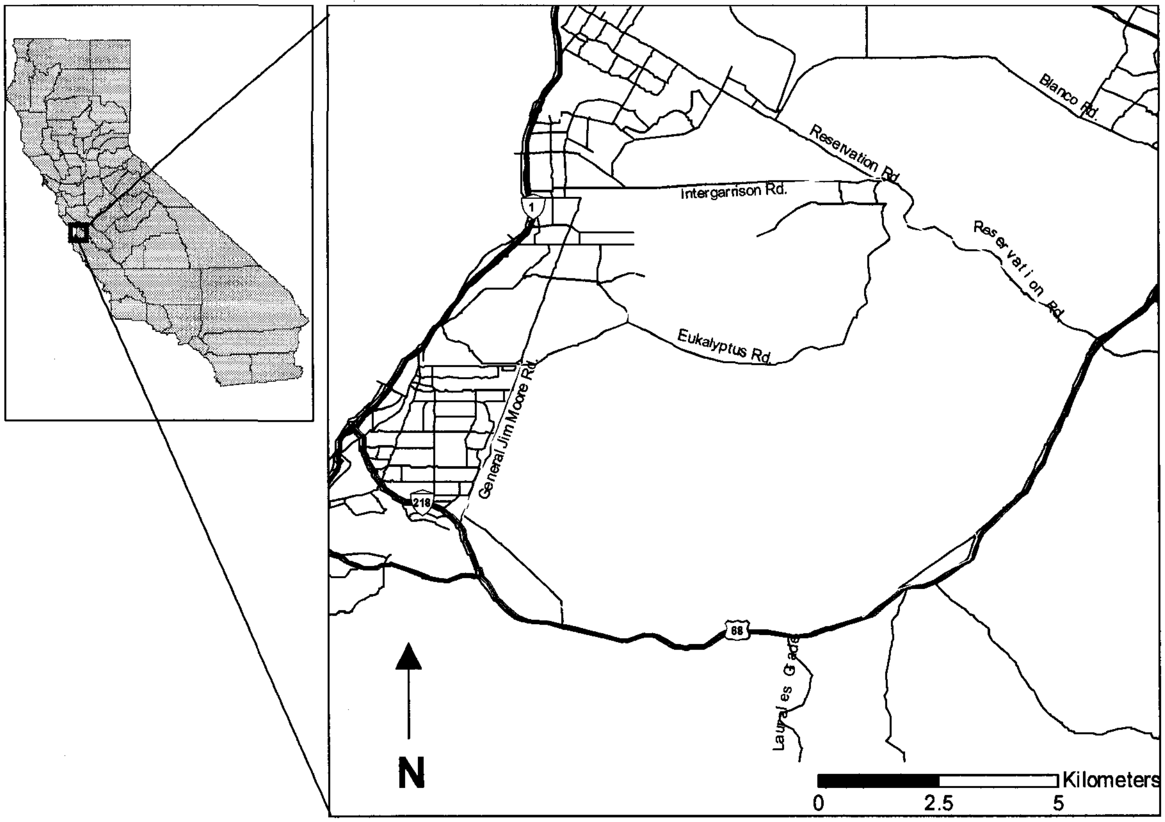

Figure 1.1: Location map of the study area in Monterey County, California, USA.

Maximum average daily temperatures in Fort Ord are between 16 and 21 degrees C, reaching the upper part of this range in the early fall (September – October) and the lower end of the range in December and January. Rainfall averages 46 cm per year, primarily falling between the months of November and March. Thick fog is prevalent during the summer months, lasting most of the night and into the early afternoon on the southeastern side of the site, and up to all day on the northwestern side.

Animal capture and handling

Active badger burrows were located by conducting daily walking and driving surveys from May-November 2005, and May-August 2006. Burrows that appeared to have been made within the previous 24 hours (soil wet, flies present, tracks observed) were set with a stopped body snare (Fig. 1.2). Snares were set in the afternoon, and checked every six hours. All badgers were captured with no apparent injuries to the animals. Most animals appeared calm within an hour after initial capture, and remained calm during captivity and further handling. Trapped badgers were restrained with a handling pole and transferred first to a large canvas bag, then to open-topped, 55-gallon barrels for transport to a veterinary clinic.

Each badger was surgically implanted with a Telonics (Mesa, AZ) IMP400/L intraperitoneal transmitter weighing 85 g by qualified veterinarians. Badgers were first hand-injected with an intramuscular injection of tiletamine and zolazepam (Telazol®, Fort Dodge) administered at a dose of 3 mg/kg. When the animal was minimally responsive, general anesthesia was induced using a mask with a mixture of isoflurane and oxygen at 3% for induction and 1-2% for maintenance, delivered via a vaporizer.

Badgers were intubated with an endotracheal tube to ensure a clear airway during surgery. The radiotransmitter implant was inserted freely into the lower right quadrant of the abdominal cavity via an incision caudal to the umbilical scar. Measurements, hair and blood (10 ml) samples were taken, and animals were subcutaneously implanted with uniquely numbered PIT tag between the shoulder blades. Body temperature, heart rate, respiratory rate, and oxygen saturation were monitored and recorded during the entire anesthetic period every 5 minutes. Heating pads were used to correct temperature abnormalities. Enrofloxin (Baytril™, Bayer HealthCare, Research Triangle Park, North Carolina) at a dosage of 7.5 mg/kg, benzyl penicillin at a dosage of 40,000 IU/kg, and carprofen (Rimadyl™, Pfizer, New York, New York) at a dosage of 2.2 mg/kg were injected subcutaneously intra-operatively to relieve pain, minimize swelling, and to prevent infection. All surgeries went smoothly, without incident. Badgers fully recovered from surgery within 3-6 hours and were then transported back to the burrow capture site for release. All study animals were checked once daily via radiotelemetry during the first 48 hours post-capture (and post-surgery placement). All animals were active (foraging, digging new dens) within a day after their release. Thereafter, animals were located at minimum once weekly via radio telemetry.

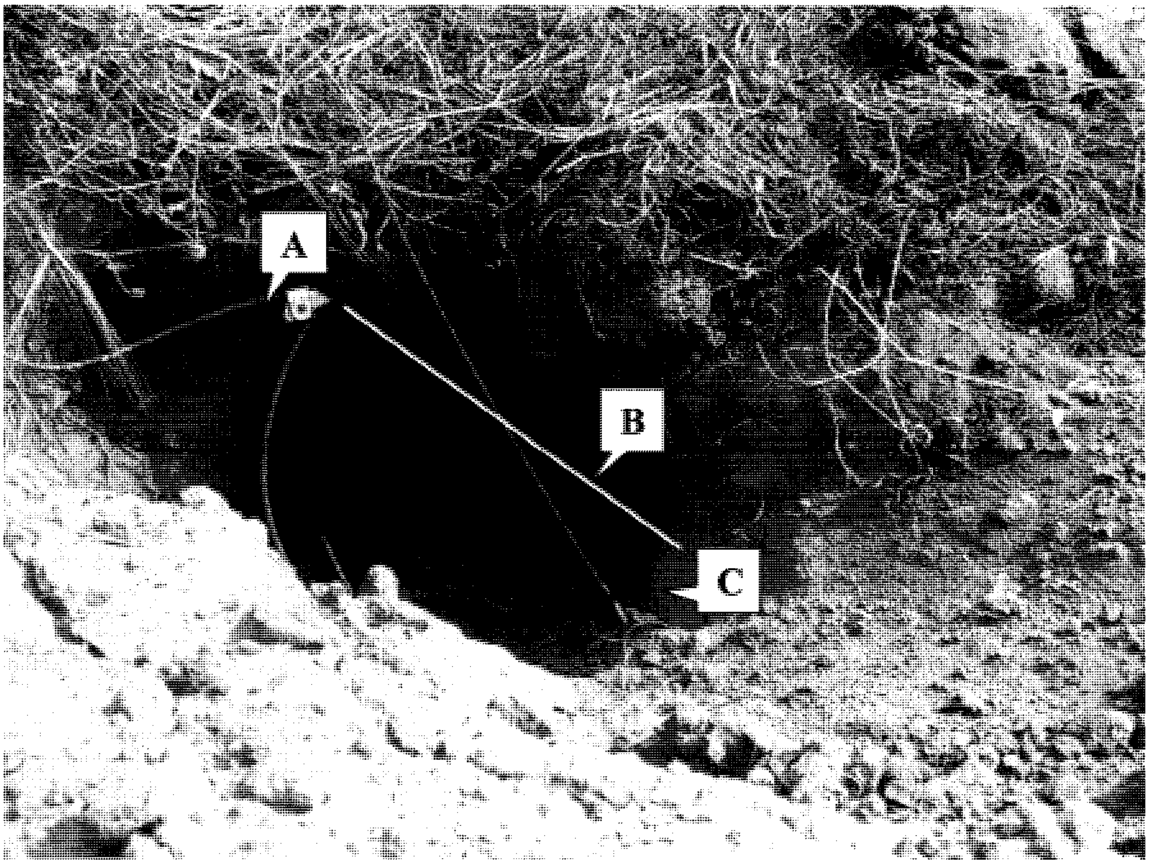

Figure 1.2: Body snare trap set. A loop of cable is set in an active burrow entrance and anchored in place by a coil of bailing wire wrapped around a thicker wire anchor that is driven into the side of the burrow (A). A piece of fishing line (drawn here [B] as it is not visible in the photograph) is tied from the one-way sliding lock to the opposite edge of the snare loop. The line catches on the badger's shoulder as the badger walks through the snare loop (head and one foot on one side of the line, other foot on the other side), thus pulling the snare shut around the animal's chest as the animal moves forward. The lock is stopped from closing the snare to a loop of a diameter less than 15 cm by a piece of wire (a "stop") pinched on the snare cable (C). The other end of the snare cable (not shown) is staked into the ground approximately 1 m away with two 40 cm rebar stakes.

Radio tracking

Radio tracking was conducted at all hours of the day and night. Observers located animals using an R-1000 receiver (Communication Specialists, Orange, California, USA); first by vehicle with a non-directional roof-mount antenna, then on foot using a hand-held 3-element directional Yagi antenna. To locate an animal, the compass bearing of the radio signal from that animal was recorded from at least two stations that were marked using a global positioning system (GPS, Garmin Inc.). Bearings for one location were taken as simultaneously as possible (never more that 15 minutes apart), and animal location was estimated by triangulation using LOAS 3.01 telemetry software (Ecological Software Solutions, Urnäsch, Switzerland). Error was minimized by using only azimuths that differed by 30-150 degrees. Triangulation error was estimated by conducting trials ($n = 40$) in which an observer triangulated the location of a hidden transmitter, and then compared this location with the transmitter's actual location. Estimated error averaged 67.70 m (range 1.0 - 245 m). During the day, animals were also located on foot by homing in on the transmitted signal. Badger radio locations were identified as either active animals (animal moving as determined by radio signal modulation), inactive animals (animal not moving but den not observed) or den (den located by the observer) locations, and were then digitized in a GIS using two separate data layers.

Data analysis

Only animals with more than 20 radio locations were included in analyses. Home range polygons were estimated using the fixed-kernel (Worton 1989) and minimum convex polygon (Mohr 1947) methods, using the Home Range Extension (Rogers and

Carr 1998) for ArcGIS version 9.0 (ESRI, Redlands, Califonia, USA). One hundred percent minimum convex polygons (MCP) were generated primarily for comparison with other studies. Kernel home range polygons (95% utilization distribution) were used for all other analyses. Kernel polygons were smoothed by calculating a smoothing value (h_{ref}) that was based on the bivariate normal probability density function used to generate the utilization distribution: $h_{ref} = n^{-1/6}\sqrt{\frac{\mathrm{var}_x + \mathrm{var}_y}{2}}$

where n is the number of points, var_x is the variance in x coordinates, and var_y is the variance in y coordinates (Worton 1989).

The MCP and 95% kernel home range sizes were compared between males and females using ANOVA. Both home range estimates were log-transformed to achieve normality and homogeneity of variances. Statistical analysis was performed using JMPin, version 5.1 software (SAS Institute, Cary, North Carolina, USA).

Habitat composition was determined using GIS data layers of land cover, vegetation, slope, soil type, road proximity, and trail proximity. The vegetation layer, obtained from Monterey County, was derived from the Landsat 7+ Thematic Mapper satellite data (June 1999). Throughout the process of spectral analysis, land cover classification was refined by visiting randomly selected points within the mapping area and recording the land cover (i.e. vegetation community) in which it occurred or, if inaccessible, identifying those points on aerial photographs (circa 1995). Polygons that could not be distinguished through spectral analysis were ground-truthed on foot or by aerial photos and assigned a classification (G. Foss, *pers. comm.*). The resulting map had an accuracy of approximately 30 meters. I consolidated land cover classes into 8 types: annual grassland, native grassland, scrub (coastal sage scrub and baccharis scrub), maritime chaparral, oak (including oak woodlands and valley oak savanna), wet (including riparian, marsh and wetland), urban (including a small amount of conifer habitat that occurred in landscaping adjacent to the urban boundary), and agriculture.

The slope data layer was obtained from the Central Coast Joint Data Committee. In this layer, slope was derived from USGS 1:24,000 digital elevation models by calculating the maximum rate of change from neighboring cells (10-meter cell size). The raster layer was then used to create a polygon layer (10 m polygons) in which each cell was assigned to one of 6 slope classes: 0-5%, 6-10%, 11-15%, 16-30%, 31-50%, and >50%. Soil data were obtained from the Natural Resource Conservation Service. I classified soil types by the dominant texture and composition into 7 classes: loams, clays, sands, hydric (soils that flood), mixes (sand/loam), xerorthents (tailings and other eroded soils), and badlands (eroded clays). Trail proximity was derived from U.S. Census Bureau's TIGER roads layer. Where needed, I added trails manually by referencing USGS 1:24,000 digital orthophotoquadrangles. Trails were then buffered in ArcGIS to create proximity polygons at 6 distance classes: <50 m, 51-150 m, 151-250 m, 250-350m, 350-550m, and >551m.

All layers were projected into the Universal Transverse Mercator coordinate system, using the 1983 North American datum. For the purposes of analyzing habitat preferences, active animal locations and den locations were buffered using a 25-meter radius to account for both the error in triangulated locations and the resolution of the GIS layers (Rettie & McLoughlin 1999). Ninety-five percent kernel polygons were used to denote each animal's home range, and the study area was defined as the combined area of all the home ranges, with an additional buffer of 500 m (approximately half the radius of the smallest home range). Use/availability data layers (buffered den points, buffered active animal points, 95% kernel polygons, and study site polygons) were used to "clip" each habitat layer; and the percent composition of each habitat type in each use/availability layer was calculated.

I analyzed habitat preference by comparing the habitat used by badgers with the habitat available to them, using compositional analysis (Aebicsher *et al.* 1993) on two scales: third-order preference and second order preference (sensu Johnson 1981). At the fine scale, third order preference measures the composition of 25 m buffer areas around radiolocations compared with the composition of that home range. Second-order preference measures the composition of home ranges compared with the composition of the study area. First order preference, composition of study are compared to the composition of the landscape, was beyond the scope of this study. Compositional analysis uses each individual's utilization distribution, rather than each radiolocation, as the sampling unit. This method avoids non-independence of the proportions that comprise habitat composition, and also correctly describes the habitat selectivity of the study population rather than that of individual animals. The resulting test statistic approximates a Chi-squared distribution, which is then used to compare observed habitat usage with that expected based on habitat availability. If observed habitat use differed significantly from expected use ($P< 0.05$), then habitats were ranked in order of preference, and paired t-tests compared use between all possible pairs of habitat types. The "agriculture" land cover class was only considered in the second-order preference analysis as it did not occur within any of the animals' home ranges, but did occur within the study site.

Because preference for one aspect of the habitat may reflect preference for a different habitat attribute with which it is correlated, relationships between groups of variables were assessed with a G-test (Sokal & Rohlf 1995) using 1000 randomly generated points within the study area. Where necessary to assure that more than 20% of the cells in contingency tables had at least 5 observations, preferred habitat classes were pooled into groups that were significantly different from each other in paired t-tests before analysis.

RESULTS

Ten badgers (six females and four males) were trapped during the course of the study. Badgers were tracked between 17 May 2005 and 18 December 2006, for periods of 2 to 20 months. The data from one badger, from which I collected only 11 locations, were excluded from home range analysis. Between 51 and 160 locations were available for the rest of the animals (Table 1.1).

Table 1.1: Summary of radio-tracking data collected for *Taxidea taxus*, Fort Ord Public Lands, California. MCP= minimum convex polygon, kernel= fixed kernel polygon, 95% utilization distribution.

Frequency	Sex	Date of capture	Days tracked	Number of fixes (dens, active)	100% MCP (km^2)	95% kernel (km^2)	Date deceased
151.400	M	5/14/2005	581	160 (50, 110)	5.31	8.05	--
151.170	F	5/25/2005	571	150 (47, 103)	1.19	1.49	--
151.340	F	5/25/2006	324	51 (12, 39)	3.56	5.28	Contact lost after 3/17/2006 [1]
151.310	F	6/15/2005	549	85 (15, 70)	1.02	1.10	--
151.370	F	6/24/2005	433	89 (22, 67)	1.88	2.82	9/5/2006 [2]
151.150	M	8/18/2005	486	51 (7, 44)	14.60	11.51	--
151.440	M	8/22/2005	483	111 (32, 79)	17.69	24.82	--
151.730	F	10/25/2005	417	99 (30, 69)	2.07	2.27	--
151.780	F	11/5/2005	162	11 (5, 6)	--	--	4/11/2006 [3]
151.880	M	5/30/2006	201	82 (26, 56)	7.30	7.28	--

[1] Carcass found 25 June 2006; cause of death unknown

[2] Found dead in burrow 6 September 2006, due to complications with radio transmitter (Quinn *et al.* in prep)

[3] Insufficient data for home range analysis.

Home ranges of animals in our study were between 1.10 and 24.82 km^2 (mean 7.18, SD 7.47) for kernel estimates, and 1.02 and 17.69 km^2 (mean 6.17, SD 6.11) for MCP estimates. Mean kernel home range size was 2.59 km^2 (SD 1.64) for females and 12.92 km^2 (SD 8.15) for males; mean MCP estimates were 1.94 km^2 (SD 1.00) for females and 11.23 km^2 (SD 5.88) for males. Both kernel and MCP home ranges were significantly larger for males than females (kernel: $F_{1,7} = 17.28$, $P = 0.004$; MCP: $F_{1,7} = 24.16$, $P = 0.002$). Home ranges of three of the females overlapped; however, these animals may have been related. Home ranges of the other females in the study did not overlap. Males' ranges overlapped between 1 and 4 female home ranges, as well as the ranges of other males (Fig. 1.3).

At the second-order scale (composition of home ranges compared with the composition of the study area) composition of badger home ranges differed significantly from that of the study site for vegetation ($\chi^2 = 37.72$, d.f. = 7, $P < 0.001$), soils ($\chi^2 = 29.88$, d.f. = 6, $P < 0.001$), and proximity to trails ($\chi^2 = 17.04$, d.f. = 5, $P < 0.004$). The most preferred vegetation types at this scale, in order of preference, were annual grassland, oak woodland, scrub, and wetland/riparian. Agriculture was least preferred, followed by urban and mixed chaparral. In paired t-tests, only some of these preferences were significant (Table 1.2). Compositional analysis also indicated a preference for sandy soils, followed by mixes of sand and loam, loams, and hydric soils. Clays were the least preferred soil type, followed by badlands and xeronthents. Badger home ranges were also at closer proximities to trails than expected; all distance classes were preferred over distances of greater than 501 m. Only moderate preference was detected for slope ($\chi^2 = 10.38$, d.f. = 5, $P = 0.070$) (Table 1.2).

Preferred vegetation types were positively associated with preferred soils ($\chi^2 = 24.02$, d.f. = 1, $P < 0.001$) and preferred distances from trails ($\chi^2 = 7.45$, d.f. = 1, $P = 0.006$). Preferred distances from trails were not associated with preferred soils ($\chi^2 = 3.33$, d.f. = 1, $P = 0.068$) (Table 1.3).

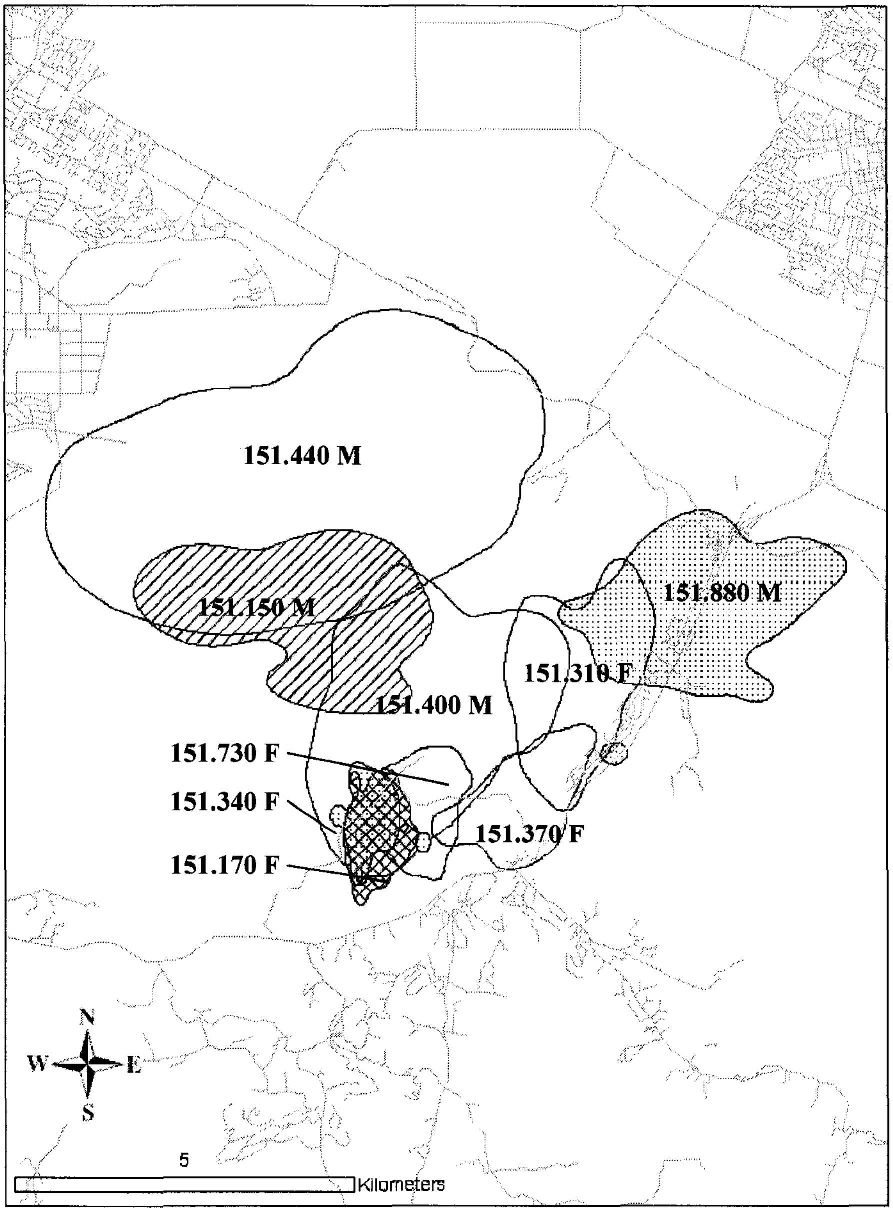

Figure 1.3: Ninety-five percent kernel home range polygons of *Taxidea taxus*, Fort Ord Public Lands, California. Polygons are labeled with animal frequency and sex (m =male, f=female). Some overlapping polygons are shaded for visual clarity.

Table 1.2: Habitat rankings for *Taxidea taxus* comparing composition of home ranges to that of the study site (second-order preference). Within each landscape characteristic, habitat classes labeled with the same letter were not significantly different in paired t-tests. Where use of a particular landscape characteristic did not differ significantly from random, rankings are labeled with "x." "n/a" = not applicable.

Rank	1	2	3	4	5	6	7	8
Vegetation	Annual grassland A	Oak woodland A	Coastal scrub A	Riparian/ wetland AB	Native grassland ABC	Urban BC	Maritime chaparral BC	Agriculture BC
Soil	sandy A	mixes A	loams A	hydric AB	xeronthents B	badlands B	clays BC	n/a
Slope	x	x	x	x	x	x	x	x
Distance to trail (m)	<50 A	51-150 A	151-250 A	251-350 A	351-500 A	>501 B	n/a	n/a

Table 1.3: Contingency table of relationships between preferred habitat classes for *Taxidea taxus* (significant different in paired t-tests for home ranges within the study site); percent of points, and expected vs. observed number of points, in each pair of classes.

Habitat class		Preferred vegetation (annual grassland, oak woodlands, scrub)	Non-preferred vegetation (urban, agriculture)	Preferred trail proximity (0-500 meters)	Non-preferred trail proximity (>500 meters)
Preferred soil types (sandy, loams, mixes)	% points	5.1	8.9	12.0	2.2
	observed	47	82	115	21
	expected	72.7	56.3	121.4	14.6
Non-preferred soil (xeronthents, badlands, clays)	% points	51.3	34.8	77.3	8.6
	observed	473	321	115	82
	expected	447.3	346.7	121.4	88.4
Preferred trail proximity (0-500 meters)	% points	51.5	37.5	--	--
	observed	489	356	--	--
	expected	478.9	369.1	--	--
Non-preferred trail proximity (>500 meters)	% points	4.8	6.2	--	--
	observed	46	59	--	--
	expected	59.1	45.8	--	--

Third order selection (composition of radiolocations within a home range compared with the composition of that home range) was analyzed separately for active locations and den locations. When active, badgers showed a significant preference for slope ($\chi^2 = 13.49$, d.f. = 5, $P < 0.019$) and trail proximity ($\chi^2 = 17.26$, d.f. = 5, $P < 0.004$). Badgers preferred intermediate slope classes over steeper slopes; other preferences were not significantly different in paired t-tests. Preference for trail proximity was significant though not linear; badgers preferred to be 51-250 m from trails. Use of vegetation and soil types was not significantly different from random (vegetation: $\chi^2 = 7.35$, d.f. = 7, $P = 0.393$; soil: $\chi^2 = 9.70$, d.f. = 6, $P = 0.138$) (Table 1.4). Trail proximity and slope were not related ($\chi^2 = 28.65$, d.f. = 25, $P = 0.279$) (Table 1.5).

Table 1.4: Habitat rankings for *Taxidea taxus* comparing composition of active locations to that of the home range (third-order preference). Within each landscape characteristic, habitat classes labeled with the same letter were not significantly different in paired t-tests. Where use of a particular landscape characteristic did not differ significantly from random, ranking are labeled with "x." "n/a" = not applicable.

Rank	1	2	3	4	5	6	7
Vegetation	x	x	x	x	x	x	x
Soil	x	x	x	x	x	x	x
Slope	31-50% A	16-30% A	6-10% A	11-15% A	0-5% AB	51% B	n/a
Distance to trail (m)	51-150 A	151-250 A	351-500 AB	<50 B	251-350 AB	>501 AB	n/a

Table 1.5: Contingency table of relationships between preferred habitat classes for *Taxidea taxus* (significant different in paired t-tests for active locations within the home range); percent of points, and expected vs. observed number of point, in each pair of classes.

Habitat class		0-5% slope	6-10% slope	11-15% slope	16-30% slope	31-50% slope	>50% slope
<50 m from trail	% points	8.0	8.7	6.4	11.0	4.0	0.0
	observed	80	87	64	110	40	0
	expected	85.3	86.9	62.5	118.1	27.8	0.4
50-150 m from trail	% points	1.9	2.5	2.0	3.4	4.0	0.1
	observed	19	25	20	34	4	1
	expected	23.1	23.5	16.9	31.9	7.5	0.1
151-250 m from trail	% points	4.1	4.3	2.4	5.3	0.8	0.0
	observed	41	43	24	53	8	0
	expected	37.9	38.5	27.7	52.4	12.3	0.2
251-350 m from trail	% points	3.1	2.4	1.9	4.8	0.9	0.0
	observed	31	24	19	48	9	0
	expected	29.3	29.9	21.5	40.6	9.6	0.1
351-500 m from trail	% points	2.0	2.4	2.0	3.9	0.4	0.0
	observed	20	24	20	39	4	0
	expected	24.0	24.4	17.5	33.2	7.8	0.11
>500 m from trail	% points	3.3	2.5	1.7	2.6	0.8	0.0
	observed	33	25	17	26	8	0
	expected	24.4	24.9	17.9	33.8	8.0	0.11

Third-order selection of den locations indicated non-random use of vegetation ($\chi^2 = 15.08$, d.f. = 6, $P = 0.020$), slope ($\chi^2 = 17.68$, d.f. = 5, $P = 0.003$), and trail proximity ($\chi^2 = 34.77$, d.f. = 5, $P < 0.001$). Animals preferred to den in native grassland and scrub habitat, and tended to avoid wetland/riparian and urban areas. Badgers also tended to den on intermediate slopes while avoiding flat (0-5%) slopes. No preference for soil type was detected ($\chi^2 = 9.88$, d.f. = 6, $P = 0.125$) (Table 1.6). Preferred habitat types were associated with preferred slope classes ($\chi^2 = 59.96$, d.f. = 1, $P < 0.001$), but not with trail proximity ($\chi^2 = 1.54$, d.f. = 1, $P = 0.215$) (Table 1.7).

Table 1.6: Habitat rankings for *Taxidea taxus* comparing composition of den locations to that of the home range (third-order preference). Within each landscape characteristic, habitat classes labeled with the same letter were not significantly different in paired t-tests. Where use of a particular landscape characteristic did not differ significantly from random, ranking are labeled with "x." "n/a" = not applicable.

Rank	1	2	3	4	5	6	7
Vegetation	Native grassland A	Coastal sage scrub A	Annual grassland AB	Oak woodland AB	Mixed chaparral AB	Urban B	Riparian /wetland B
Soil	x	x	x	x	x	x	x
Slope	16-30% A	11-16% A	6-10% A	31-50% AB	51% AB	0-5% B	n/a
Distance to trail (m)	51-150 A	151-250 A	351-500 A	<50 A	251-350 A	>500 B	n/a

Table 1.7: Contingency table of relationships between preferred habitat classes for *Taxidea taxus* (significant different in paired t-tests for den locations within the home range); percent of points, and expected vs. observed number of point, in each pair of classes.

Habitat class		Preferred vegetation (native grassland, scrub)	Non-preferred vegetation (urban, riparian/ wetland)
Preferred slope (6-30%)	% points	1.52	40.91
	observed	2	54
	expected	21.56	34.35
Non-preferred slope (0-5%)	% points	37.12	20.45
	observed	49	27
	expected	29.36	46.63
Preferred trail proximity (0-500 meters)	% points	41.50	48.98
	observed	61	72
	expected	58.81	74.19
Non-preferred trail proximity (>500 meters)	% points	2.72	6.80
	expected	4	10
	observed	6.19	7.81

DISCUSSION

Home range size

Badger home ranges in this study were within the range of those previously reported in the literature. The average MCP home range sizes of 1.94 km^2 for females and 11.93 km^2 for males were larger or similar in size to those reported in Idaho, (m: 2.4 km^2, f: 1.6 km^2; Messick & Hornocker 1981), Wyoming (m: 8.0 km^2, f: 3.0 km^2; Minta 1993), Utah (m: 5.8 km^2, f: 2.4 km^2; Lindzey 1978), and Texas (m: 7.02 km^2; Collins 2003). The home range estimates; however, were considerably smaller than many others reported in the literature, which reported MCP home ranges of between 9 and 65 km^2 for females and between 44 and 541 km^2 for males (Sargeant & Warner 1972, Lampe & Sovada 1981, Warner & VerSteeg 1995, Newhouse & Kinley 2000, Hoodicoff 2003).

The variation in home range size between these studies likely reflects variation in resource availability and quality between the study sites. Primary productivity (which often scales with latitude) also relates to home range size in carnivores, such that those found at more northern latitudes can have larger ranges than more southerly populations (Gomper & Gittleman 1991). As with many species, badgers utilizing resources that are temporally or spatially dispersed may tend to have larger home ranges. In British Columbia, for example, at the northern extent of their range, badgers prey primarily on Columbian ground squirrels (*Spermophilus columbianus*), which are an extremely patchy resource. Thus home range sizes in British Columbia would be expected to be among the largest. At Fort Ord, which is much nearer the southern extent of their range, badgers seem to be primarily subsist on gophers and voles, which are an abundant and relatively homogeneous resource. They also were observed to feed opportunistically on bird eggs and wasp nests. Moreover, a majority of the soils at Fort Ord are extremely sandy and friable, perhaps further reducing the distance badgers have to travel to locate suitable habitat. Minta (1993) reports the abundance and distribution of females as being an important determinant of male badger home range patterns. Badgers have a polygamous mating system, which in many species of solitary carnivores results in males and having much larger and more overlapping ranges than do females due to mate searching (Sandell, 1989; Minta, 1993). Such a pattern was evident in this study (Fig. 1.3).

Habitat preference

Habitat preferences differed slightly at the different scales of analysis, as well as between den placement and active locations. These differences indicate scale-dependent selection as well as different requirements for each activity.

Vegetation preference

At the scale of the whole study area, badgers' home ranges tended to be sited in grasslands, a finding that is consistent with that reported by Apps *et al* (2002) and Hoodicoff (2003). Home ranges observed in this study were also preferentially located in coastal sage scrub and oak woodland habitat. Because preferred vegetation types were associated with preferred soil types, selection at this scale could reflect a preference for either of these factors.

Badgers at Fort Ord were less selective for vegetation in their active locations than for den placement; active locations indicated no preference for any of the vegetation types within their home range. Badgers are opportunistic foragers (Messick & Hornocker

1981, Lampe 1982, Lindzey 1982, Goodrich & Buskirk 1998, Sovada *et al.* 1999), and thus could probably attempt to find prey in a wide range of vegetation types. Moreover, as was reported by Hoodicoff (2003), individual variation in preference while active (stemming from differences in mobility or prey preferences) may have obscured general habitat preferences for the study population. For den placement within their home ranges; however, badgers preferred native grasslands and coastal sage scrub over annual grasslands. Preference of these habitat types may be indicative of an attraction to the cover provided by scrub habitat; many species rest or retreat in covered areas for protection from predators. Badgers may also have been attracted to other conditions that are favorable to both vegetation types, as both scrub and native grasslands were associated with steeper slopes at Fort Ord. As Fort Ord is seasonally grazed by sheep, areas with steep slopes or good vegetative cover may be less impacted by grazing practices that might compact the soil, reduce small mammal abundance and deter badger denning. Placing dens on steep slopes or in cover may also deter potential predators such as coyotes and mountain lions from locating sleeping badgers. Finally, badgers often dig their sleeping den where they have been hunting immediately before (Minta 1990). Thus, native grassland and coastal sage scrub might more frequently be the locations of successful foraging attempts due to higher prey abundances there. To conduct an analysis of badger diet and small mammal abundance and distribution at Fort Ord was beyond the scope of this project; however, such an analysis would probably add to the understanding of this pattern.

Both Hoodicoff (2003) and Apps *et al.* (2002) found that badgers were often positively associated with human-modified landscapes. However, at Fort Ord, badgers avoided agriculture and urban areas at the scale of the study site, and avoided urban areas within the home range for denning (because no home ranges contained agricultural habitat, third-order preference was not analyzed). The fact that the animals were all trapped within a natural area may bias results toward animals that avoided human-altered habitats. Moreover, the agriculture available within the study area (as was defined for analysis) was separated from Fort Ord by a 2-lane highway that may have functioned as a deterrent to the badgers' use of agricultural land (although one of the study animals regularly crossed another busier road to reach grassland habitat on the opposite side). On the larger scale, a higher probability of mortality experienced in agricultural and urban landscapes may affect the distribution of badger home ranges. In California, badgers are regularly trapped as a pest in agricultural and residential areas (Minta & Marsh 1988), which would thus limit the inclusion of these areas in badger home ranges as well as the ability of badgers to disperse through them. For den placement, badgers' avoidance of urban habitats may be due to disturbance by domestic animals and humans; however, it may also reflect an aversion to flat slopes (see *Slope and trail preference*, below).

Soil preference

Badgers home ranges were associated with sandy soils, loam/sand mixes, and loams; and avoided badlands, eroded soils, and clays within the study site. However, they showed no preference for soil type at the third-order scale of analysis for active or den locations. This result was surprising, as it was expected that soil composition would be more likely to influence the day to day digging habits than to influence selection at larger scales. On the larger scale, these preferred soils were associated with preferred vegetation types, and thus their preference may reflect the avoidance of urban and agricultural landscapes at this scale. On the finer scale, it is possible that the physical effort of digging in a particular soil type is not limiting to badger foraging or denning behaviors. Other factors not tested here, such as the presence of prey, may be more important. Similarly, Hoodicoff (2003) found no strong selection for soil type at the home range scale. Apps *et al.* (2002); however, found that badgers preferred fine, sandy loams with low coarse fragment content and good drainage at a fine scale. In British Columbia, which is the northern extent of the badger's range, a stronger preference for soil type may reflect the lower quality of resources there (Apps *et al.* 2002). Although the soils at Fort Ord varied in texture and drainage, it may be that even the most poorly drained and/or coarse soils were still favorable enough for digging. That badgers preferred sandy, loamy and mixed soil types on the larger scale may support such a conclusion—home ranges were already situated within optimal digging substrate, thus varied soil types could be used within those home ranges.

Slope and trail preference

Badgers responded more strongly to slope at the finer scale. They showed a consistent avoidance of both steep slopes (> 51%) and flat terrain (0-5%) for both active locations and den placement; with active locations avoiding steep slopes and den placement significantly avoiding flat terrain. In general, as an animal's mass increases, the maximum angle at which they will ascend a hillslope decreases (Reichman & Aitchison 1981, Wall *et al.* 2006). Steep slopes may thus be energetically difficult to navigate for active badgers, and may also be avoided by their prey. The avoidance of flat terrain for denning is likely to be associated with energetics as well: digging vertically into flat ground requires the removal of soil against the force of gravity, where digging horizontally does not. Again, preference for intermediate slopes may also reflect an association with the presence of their burrowing prey (i.e. gophers), as the energetic relationships with slope may be the same for both species. Burrows dug in flat ground may also be more subject to flooding and poor drainage.

At the larger scale of analysis, and for den placement within the home range, badgers exhibited an avoidance of areas more distant from trails. On the scale of the study site, this result may be linked to dispersal: trails may facilitate badgers' long distance movements while siting their home range. However, it is equally likely that as trails occurred in the study site, but not in the surrounding urban and agricultural areas, badgers' association with trails reflects an association with Fort Ord in general. At the finer scale, trails may facilitate badger movement across their home range, and ultimately, to den locations. While active, badgers selected habitat some distance from trails (51-250 meters), more than habitat within 50 meters of trails. This pattern could reflect an avoidance of human activity. The network of trails at Fort Ord experiences low to moderate levels of use for recreation; primarily biking, hiking, and horseback riding. As most of this human activity takes place during the day, badgers' nocturnal behavior allows them to avoid encountering a majority of it; however, scents of humans, horses, and domestic dogs associated with trails may still deter them from spending much time at the closest proximity. Although I did not find any relationship between trail proximity and vegetation, slope, or soil; it is possible that some landscape feature that I did not quantify that favors trail construction may incidentally favor badgers and their prey. Finally, badgers' association with trails could reflect a bias in my sample toward animals using habitat that was accessible from trails , as searching for trap locations commenced from trails. Additionally, badger locations near trails may have been easier to obtain as most of the radio telemetry was conducted from trails, and distant badger signals were occasionally obscured by the hilly terrain.

Management implications

California grasslands are among the least protected habitats in the state—less than 10% have at least moderate levels of protection from development—and are considered among the highest priority for conservation (Davis *et al.* 1998, Olsen & Cox 1999). In the Central coast area, despite being among the most widely distributed habitat types, only 2.84% of grasslands were protected as of 1998 (Davis *et al.* 1998, Olsen & Cox 1999). As part of a regional approach to managing this landscape, steps should be taken to maintain the most wide-ranging carnivores within it. American badgers, due to their association with grasslands on the larger scale can serve as a suitable focal species in this respect. Badger home range sizes and habitat preferences determined in this study underscore the need for large (at least >30 km^2 to accommodate the home range of a few breeding males) core areas of grassland habitat buffered from human-modified landscapes. Though females may be able to persist in comparatively small habitat fragments due to their smaller home range sizes, populations will only be maintained if males can reach those fragments from adjacent areas to mate. In the case of Fort Ord in particular, the protected area is currently almost entirely surrounded by human development. The abundant resources and relatively small home range sizes of the female badgers at Fort Ord may have thus far insulated the population from the effects of large-scale fragmentation of the habitat; however, the preservation or creation of corridors may be necessary to maintain the population in the long term.

In managing habitat for badgers on smaller scales, consideration of activity-specific habitat preferences should determine the optimal design and configuration of protected areas. For example, badgers are more selective of vegetation types for denning than they are for moving. Thus, where conservation options are limited, a wide range of habitats that may be less than optimal for denning can still potentially serve as a corridor; provided that elements required for denning are maintained in adjacent core habitat. Many protected areas in California are preserved as community open space, warranting the construction and maintenance of trails for recreation. Trails may be either directly or indirectly compatible with badger presence at both fine and broad scales. However, at the smaller scale, active badgers may avoid the very nearest proximity to trails (<50 meters). Disturbance associated with trails can thus be minimized by ensuring that recreation is strictly limited to trails. Limiting trails and activity to the flattest terrain will avoid conflict with badger daytime dens on slopes; and perhaps less important, activities on the steepest terrain will avoid active badgers if night time recreation occurs.

Badgers are widespread throughout California, although the large scale conversion of grasslands to agricultural and suburban development has likely contracted their range somewhat (Williams 1986, Larsen 1987). Due to the diversity of resource abundance and distribution in grasslands across the state, extrapolation of the results of this study to other parts of California should be exercised with caution. Where resources are more patchily distributed either spatially or temporally, or where the habitat is less productive, badgers may require much larger home ranges to meet their energetic requirements. Likewise, they may exhibit stronger habitat preferences where favorable aspects of the landscape are more limited. This study did not address the sources of mortality for badgers in fragmented habitat directly; however, mortalities due to vehicle collisions, as well as predation by coyotes and domestic dogs have been reported elsewhere (Case 1978, Messick & Hornocker 1981, Apps *et al.* 2002, Hoodicoff 2003). Badger mortality due to ingestion of rodenticides is another potential threat, though documentation of this phenomenon is anecdotal or lacking entirely (Quinn *et al. in prep*). Understanding these population dynamics will better clarify the mechanisms through which landscape fragmentation affects badger persistence, and conservation of badger habitat will only preserve populations if these other threats can be minimized.

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CHAPTER 2

FACTORS AFFECTING THE MOVEMENT BEHAVIOR OF AMERICAN BADGERS (*TAXIDEA TAXUS*)

Abstract

The way an animal moves through the landscape often varies between more preferred or less preferred habitat types. Understanding these movements can elucidate how "patchy" the animal perceives the landscape to be. However, since the mechanisms driving movement can vary between an organism's gender, life stage and/or seasonality, so may an animal's perception of patchiness. Here, I examined the movement patterns of American badgers in coastal California. Five females and 4 males were tracked using radio telemetry for periods of 2 to 20 months. Each animal was tracked for between 2 and 11 sessions. I compared the travel speed and path complexity (tortuosity) across the seasons for each sex. I then examined whether travel speed or path complexity was affected by vegetation type (indicating habitat selectivity) depending on sex or season. Badgers' travel speeds were greater in the mating season and spring season than they were in the winter for both sexes. Vegetation type only affected the travel speed of males during the fall and the spring; in the mating season travel speed was not affected by vegetation type. Females' movements were not affected by vegetation type in any season. Path complexity was not affected by sex or season, and paths were only slightly more complex in maritime chaparral, native grassland, and scrub habitats than in annual grassland and oak habitats. Increased movement in the mating season, coupled with less habitat selectivity for males, may warrant management concern for badgers moving through fragmented habitat.

INTRODUCTION

The ability or propensity of an animal to move through a landscape often determines its response to the effects of habitat fragmentation. An animal restricted to intact habitat may be incapable of colonizing distant patches because of an inhospitable landscape matrix; or it may use the matrix under some circumstances to disperse through and colonize new areas (Brooker *et al.* 1999, Cale 2002). The relative success of individuals moving through a landscape matrix can vary: some incur a cost in breeding success or mortality rates (Purcell & Verner 1998, Misenhelter & Rotenberry 2000, Pidgeon *et al.* 2003), while others experience no difference in costs compared to that experienced in contiguous habitat (Woodward *et al.* 2001, Shlaepfer 2002, Boulton & Clarke 2003). Ultimately, these factors can combine to determine landscape permeability and species distributions (Boudjemadi *et al.* 1999).

Landscape structure can affect animal movement behavior in a number of ways. Animals tend to move more slowly and less linearly through preferred habitat (Crist *et al.* 1992, Rosenberg *et al.* 1997, Stapp & Van Horne 1997, Schultz 1998, Whittington *et al.* 2003, Dickson *et al.* 2005); potentially due to lessened predation risks (Sharpe & Van Horne 1998, Selonen & Hanski 2003) and/or because of increased foraging behavior (Dickson *et al.* 2005). Various metrics have been used to describe path complexity, such as fractal dimension (With 1994) and path tortuosity (Weins *et al.* 1995). These metrics can also indicate an animal's sensitivity to habitat boundaries and landscape patchiness, and provide a measure of landscape fragmentation specific to that animal's perception (With 1994). Such information can be useful in conservation planning in determining what qualifies as core habitat for a particular species and whether the landscape matrix can support animal movement to alternative patches.

An animal's sensitivity to landscape patchiness may depend in part on an organism's gender, life stage, behavioral, or seasonal factors. For example, while most movement is characterized by the daily search for food and/or shelter, many animals exhibit long distance movements or dispersal events which are distinctly different from average daily movements. In polygamous carnivore species, males often exhibit long distance movement during the breeding season when they are searching for females (Sandell 1989). During these periods of increased movement, animals may be less selective of habitat, thereby moving (1) through more habitat types, or (2) more rapidly along more linear routes through all habitat types. Alternatively, even if distinct long-range movement behavior is not evident, habitats used for movement may still change seasonally, due to the fact that breeding opportunities, or searches for new territories may be driving movement behavior rather than food resources or predation risks alone.

I examined the influence of habitat and season on the movement paths of American badgers (*Taxidea taxus*). Because of their large home range sizes and dispersal distances (Messick & Hornocker 1981, Hoodicoff 2004, Chapter 1), as well as their extreme sensitivity to habitat fragmentation compared with other California carnivore species (Crooks 2002), badgers are increasingly being considered as a focal species for conservation planning in California grasslands. As solitary, polygamous carnivores, male badgers often have much larger ranges than do females; as the females' home range sizes are dictated by food resources while those of males are dictated by both food and access to females (Sandell, 1989; Minta, 1993). During the mating season, when males are seeking females, home ranges and daily movements can expand to up to three times their non-breeding season size (Minta 1993, Goodrich & Buskirk 1999, Collins 2003, Hoodicoff 2003). Juveniles of both sexes have been observed dispersing distances of up to 110 km in the late summer to establish ranges away from their mothers (Messick & Hornocker 1981).

Although badgers in California have been shown to select for annual grasslands and scrub habitat for overnight resting in dens, they appeared generally less selective for vegetation types while active (Chapter 1). To determine whether more fine-scale habitat preferences (e.g. during the course of a nightly movement path) are exhibited while badgers travel through the landscape, I first analyzed seasonal variation in nightly movement paths to determine when the most movement occurred. Secondly, to determine whether badgers were selective of habitat during times of increased movement (e.g. the mating season), I examined whether or not badgers moved at different speeds or degrees of path complexity when traveling through various habitat types across the seasons. Finally, because the factors driving movement may depend on the sex of the animal as well as the season, I also looked for differences in these movement patterns between the sexes.

METHODS

Study area

Research occurred in the Bureau of Land Management's (BLM) Fort Ord Public Lands in northern Monterey County, California (36.68° N 121.77° W; elevation range 20-250 m). The Fort Ord Public Lands, part of a former U.S. Army base that was closed in 1994, encompass approximately 60 km^2 of grassland, coastal sage scrub, maritime chaparral, and coastal oak woodland habitats. Approximately 30 km^2 are currently managed by the BLM for recreation; and numerous biking, hiking, and equestrian trails cross the landscape. Another 32 km^2 are currently closed to all human activity as they undergo cleanup operations for unexploded ordnance by the U.S. Army. The property is bounded on all sides by various types of human land uses: irrigated agriculture in the Salinas Valley to the east, low to high density residential development on the south and west, and the former Army base and current California State University Monterey Bay campus (CSUMB) to the north. Fort Ord also directly abuts several roads: State Highway 68 (4 lanes) to the south, General Jim Moore Boulevard (2 lanes, residential) to the west, and Reservation Road (2 lane country road) to the east and north (Fig. 2.1).

Topography in the study site varies from relatively flat upland terraces to the northwest to steep canyons and rolling hills to the southeast. The northwestern edge of the study site experiences a strong maritime influence due to its close proximity (5 km) to the Pacific Ocean. The habitat on this side of the site is characterized by dwarfed coastal oak woodlands and maritime chaparral on sandy soils. Further away from the ocean, to the southeastern side of the study site, the vegetation transitions to extensive grasslands with areas of coastal sage scrub and oak woodland and savanna habitats. Ephemeral riparian corridors and drainages in this part of the site are dominated by willow (*Salix* sp.), sycamores (*Platanus racemosa*) and oaks (*Quercus* sp.). Soils on the southeastern side of the site are more dominated by loams and clay composites.

Prey species in the site consisted primarily of gophers (*Thomomys bottae*) and voles (*Microtis californicus*) in the grasslands, kangaroo rats (*Dipodomys* sp.) in the sage scrub and chaparral, and woodrats (*Neotoma fuscipes*) in the oak woodlands. California ground squirrels (*Spermophilus beecheyi*) occurred in isolated colonies throughout the site, and were more common along the urban boundaries.

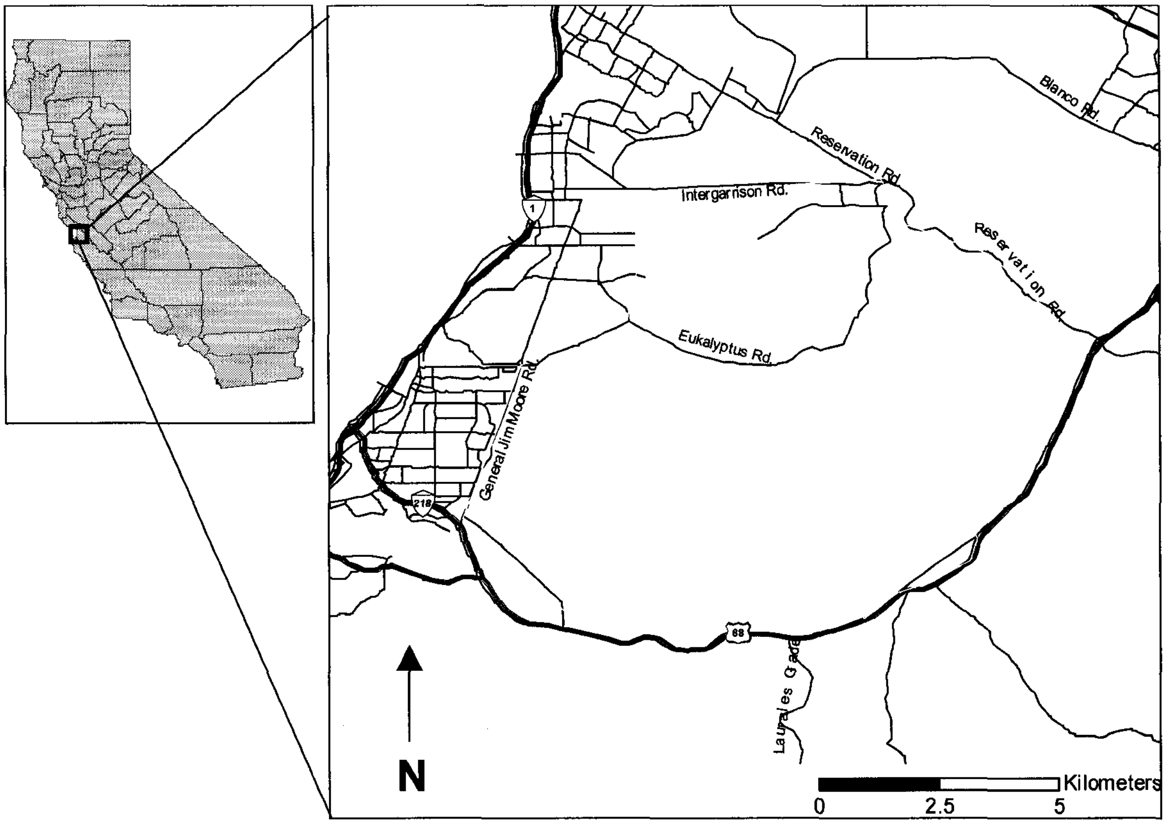

Figure 2.1: Location map of the study area in Monterey County, California, USA.

Maximum average daily temperatures in Fort Ord are between 16 and 21 degrees C, reaching the upper part of this range in the early fall (September – October) and the lower end of the range in December and January. Rainfall averages 46 cm per year, primarily falling between the months of November and March. Thick fog is prevalent during the summer months, lasting most of the night and into the early afternoon on the southeastern side of the site, and up to all day on the northwestern side.

Animal capture and handling

Active badger burrows were located by conducting daily walking and driving surveys from May-November 2005, and May-August 2006. Burrows that appeared to have been made within the previous 24 hours (soil wet, flies present, tracks observed) were set with a stopped body snare set (Fig. 2.2). Snares were set in the afternoon, and checked every six hours. All badgers were captured with no apparent injuries to the animals. Most animals were calm soon after initial capture, and remained calm during captivity and further handling. Trapped badgers were restrained with a handling pole and transferred first to a large canvas bag, then to open-topped, 55-gallon barrels for transport to a veterinary clinic.

Qualified veterinarians surgically implanted each badger with a Telonics (Mesa, AZ) IMP400/L intraperitoneal transmitter that weighed 85 g. Badgers were first hand-injected with an intramuscular injection of tiletamine and zolazepam (Telazol®, Fort Dodge) administered at a dose of 3 mg/kg. When the animal was minimally responsive, general anesthesia was induced using a mask with a mixture of isoflurane and oxygen at 3% for induction and 1-2% for maintenance, delivered via a vaporizer. Badgers were intubated with an endotracheal tube to ensure a clear airway during surgery. The radiotransmitter implant was inserted freely into the lower right quadrant of the abdominal cavity via an incision caudal to the umbilical scar. Body temperature, heart rate, respiratory rate, and oxygen saturation were monitored and recorded during the entire anesthetic period every 5 minutes. Heating pads were used to correct temperature abnormalities. Enrofloxin (Baytril™, Bayer HealthCare, Research Triangle Park, North Carolina) at a dosage of 7.5 mg/kg, benzyl penicillin at a dosage of 40,000 IU/kg, and carprofen (Rimadyl™, Pfizer, New York, New York) at a dosage of 2.2 mg/kg were injected subcutaneously intra-operatively to relieve pain, minimize swelling, and to prevent infection. All surgeries went smoothly, without incident. Badgers fully recovered from surgery within 3-6 hours and were then transported back to the burrow capture site for release. All study animals were checked once daily via radiotelemetry during the first 48 hours post-capture (and post-surgery placement). All animals were active (foraging, digging new dens) within a day after their release. Thereafter, animals were located at minimum once weekly via radio telemetry. Because access to the study site was limited during the rainy winter months (January-March), no telemetry sessions were successfully completed during that period.

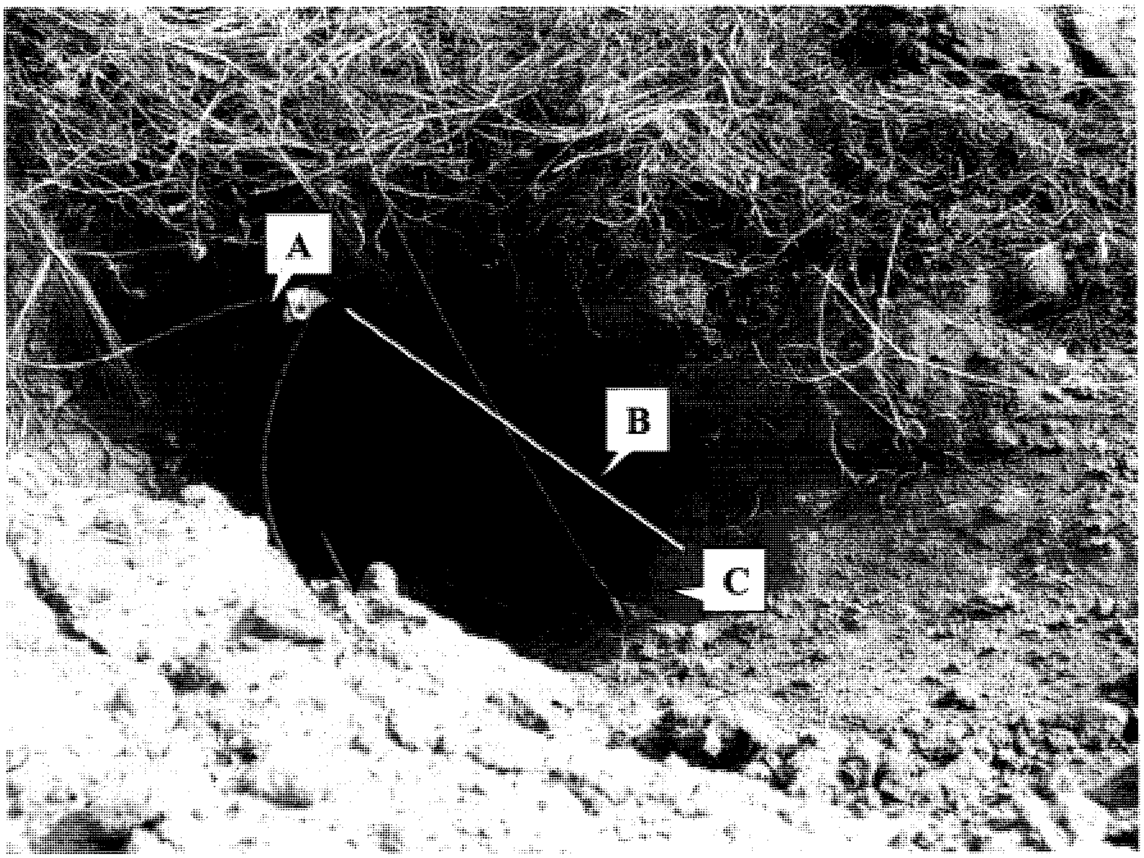

Figure 2.2: Body snare trap set. A loop of cable is set in an active burrow entrance and anchored in place by a coil of bailing wire wrapped around a thicker wire anchor that is driven into the side of the burrow (A). A piece of fishing line (drawn here [B] as it is not visible in the photograph) is tied from the one-way sliding lock to the opposite edge of the snare loop. The line catches on the badger's shoulder as the badger walks through the snare loop (head and one foot on one side of the line, other foot on the other side), thus pulling the snare shut around the animal's chest as the animal moves forward. The lock is stopped from closing the snare to a loop of a diameter less than 15 cm by a piece of wire (a "stop") pinched on the snare cable (C). The other end of the snare cable (not shown) is staked into the ground approximate 1 m away with two 40-cm rebar stakes.

Radio tracking

To determine travel paths of badgers, observers located animals using an R-1000 receiver (Communication Specialists, Orange, CA); first by vehicle with a non-directional roof-mount antenna, then on foot using a hand-held 3-element directional Yagi antenna. The specific location of the animal was determined by recording the compass bearing of the radio signal from two stations that were marked using a global positioning system (GPS, Garmin Inc.). Bearings for one location were taken as simultaneously as possible (never more that 5 minutes apart), and animal location was estimated by triangulation using LOAS version 3.01 telemetry software (Ecological Software Solutions, Urnäsch, Switzerland). Error was minimized by using only azimuths that differed by 30-150 degrees. Triangulation error was estimated by conducting trials (n = 40) in which an observer triangulated the location of a hidden transmitter, and then compared this location with the transmitter's actual location. Estimated error averaged 67.7 m (range 1.0 - 245 m). Radio tracking was conducted beginning one hour before sunset at the earliest, and continued until one hour after sunrise at the latest. An individual badger was located by one or two observers once every 15 minutes for up to 6 hours, or until the animal retreated to a den (or stopped moving) for more than one hour. If the signal was lost for more than one hour, the tracking session was terminated. Coordinates of the badger radio locations were then entered into a geographic information system (GIS) to plot them on a map. Sequential points for each tracking session were connected and turned into linear GIS features (one line per session) using the Home Range Extension (Rogers & Carr 1998) in ArcGIS (ESRI, Redlands, Califonia, USA). Only sessions that lasted at least one hour were considered in further analysis.

Data analysis

I calculated the distance and speed (the distance traveled divided by time between fixes, converted to meters per hour) between sequential locations; I refer to these hereafter as "segments." For each segment, I also calculated the percent falling in each vegetation type by overlaying the travel path data layer on a vegetation data layer in ArcGIS. The vegetation data layer was a subset of a land cover data layer obtained from Monterey County that was derived from the Landsat 7+ Thematic Mapper satellite image data (June 1999), and had an accuracy of approximately 30 meters. I consolidated the land cover classes into 8 types: annual grassland, native grassland, scrub (coastal sage scrub and *Baccharis* scrub), maritime chaparral, oak (including oak woodlands and valley oak savanna), wet (including riparian, marsh and wetland), urban (including a small amount of conifer habitat that occurred in landscaping adjacent to the urban boundary), and cultivated agriculture. Each segment was classified according to the dominant vegetation type along that segment (that which comprised more than two-thirds or 67% of the segment). Segments that were not dominated at 67% by any particular vegetation type (n = 59; 8.8% of the segments) were discarded from analysis. Each segment was also classified by the sex of the focal animal and the season in which the session was completed: mating (1 July – 30 September), fall (1 October – 31 December) and spring (1 April – 31 May).

For each session, I calculated the total path length, the average segment length, and average segment movement rate. Following Whittington *et al.* (2004), path complexity was quantified by a measure of tortuosity, calculated as the total path length (L) divided by the square of the net displacement (R) (Fig. 2.3). The percent length of each path falling in each vegetation type was calculated using the same method described for segments. Sessions were classified both by the percent composition of each vegetation type and by the dominant vegetation type (highest percentage comprising that session). Each session was also classified by the sex of the focal animal and the season in which the session was completed. Where necessary, data were log-transformed to achieve normality and homogeneity of variances.

To determine the periods of greatest movement, I analyzed the effect of season, sex and the season*sex interaction on the average movement rate in the sessions using analysis of variance (ANOVA), with animal identity considered a random effect. Next, for each sex during each season, I analyzed the effect of vegetation type (nested within "session") on the mean movement rate in the segments using ANOVA, again considering animal identity as a random effect.

In analyzing factors affecting path tortuosity, I first used a backwards stepwise procedure to extract the best subset of predictor variables that classified vegetation type, season and sex. Candidate variables with a P value of 0.25 were allowed to enter the model; a P value of 0.10 was used as the criterion to retain the variable at the conclusion of each step. The resulting model was used to determine the effect of predictor variables on path tortuosity using ANOVA.

Figure 2.3: Metrics used for path tortuosity calculation illustrated on a 2-hour tracking session for Badger 151.170. Path length (L) = sum length of line segments 1 through 8. Net displacement (R) = linear distance from point A to point B.

RESULTS

Nine badgers (five females and four males) were tracked between 17 May 2005 and 18 December 2006, for periods of 2 to 20 months. Sixty tracking sessions were included in the final analysis. Each animal was tracked for between 2 and 11 sessions; sessions lasted between 60 and 360 minutes (mean 201, SD 67). Twenty sessions were completed during the mating season, 30 were completed in the fall, and 10 were completed in the spring. Both sexes were observed across all seasons. In the final analysis 610 individual segments were included, consisting of between 18 and 129 segments for each animal. The breeding season had 210 segments, 315 were from the winter, and 85 were from the spring (Table 2.1). Ninety one percent (554 of the segments) were comprised of a single vegetation type. A majority of the sessions, and thus segments, occurred in annual grassland habitat (Fig. 2.4).

Table 2.1: Number of sessions and segments observed for each badger in each season.

	Season					
Animal I.D.	Mating		Fall		Spring	
Males	Sessions	Segments	Sessions	Segments	Sessions	Segments
151.150	1	8	1	10	--	--
151.400	2	33	8	81	1	15
151.440	1	12	4	43	3	33
151.880	3	15	1	25	1	--[1]
Male Total	**6**	**68**	**14**	**159**	**5**	**48**
Females						
151.170	6	54	4	51	1	4
151.310	1	11	3	15	1	15
151.340	1	14	3	19	--	--
151.370	3	36	2	15	--	--
151.730	3	27	4	56	3	18
Female Total	**14**	**142**	**16**	**156**	**5**	**37**
Grand Total	**20**	**210**	**30**	**315**	**10**	**85**

[1] The session was used for analysis as it was dominated by one habitat type. The individual segments; however, were not dominated by one habitat type and thus were discarded from the segment analysis.

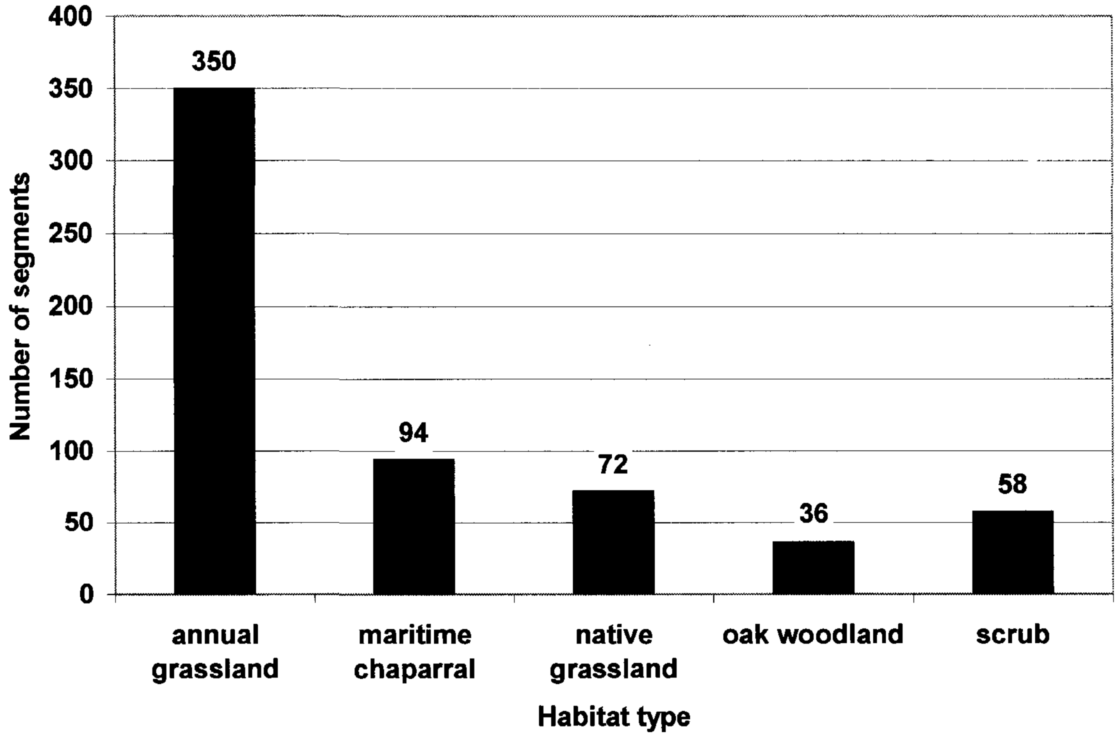

Figure 2.4: Number of segments in American badger travel paths occurring in each habitat type during continuous tracking sessions.

Badgers' travel speeds were higher in the mating season (summer) and spring season than they were in the fall ($F_{2, 7} = 7.07$, $P = 0.002$). Across all seasons, no difference was detected between the sexes ($F_{1, 7} = 1.28$, $P = 0.264$) and the sex * season interaction revealed no evidence that the seasonal variation was modified by gender ($F_{2, 7} = 1.54$, $P = 0.225$) (Fig. 2.5).

No effect of vegetation type on travel speed of females was detected during the mating season ($F_{6, 122} = 0.29$, $P = 0.94$) or the fall ($F_{6, 132} = 1.20$, $P = 0.31$). There were insufficient data to assess the effect of vegetation on the travel speed for females during the spring; females used only one vegetation type, annual grassland, during the sessions observed in this season.

There was no effect of vegetation type on travel speed of the males during the mating season ($F_{5, 57} = 0.66$, $P = 0.66$). Vegetation type did, however, affect the travel speed of males during the fall and the spring (fall: $F_{7, 7} = 2.50$, $P = 0.020$; spring: $F_{3, 7} = 4.47$, $P = 0.008$). The relationship between travel speeds and specific vegetation types for males during these seasons was not consistent; vegetation types that were traveled through more quickly than other vegetation types by one individual were traveled through more slowly than other types by another individual. Moreover, this pattern differed between the seasons for a given individual (Fig. 2.6).

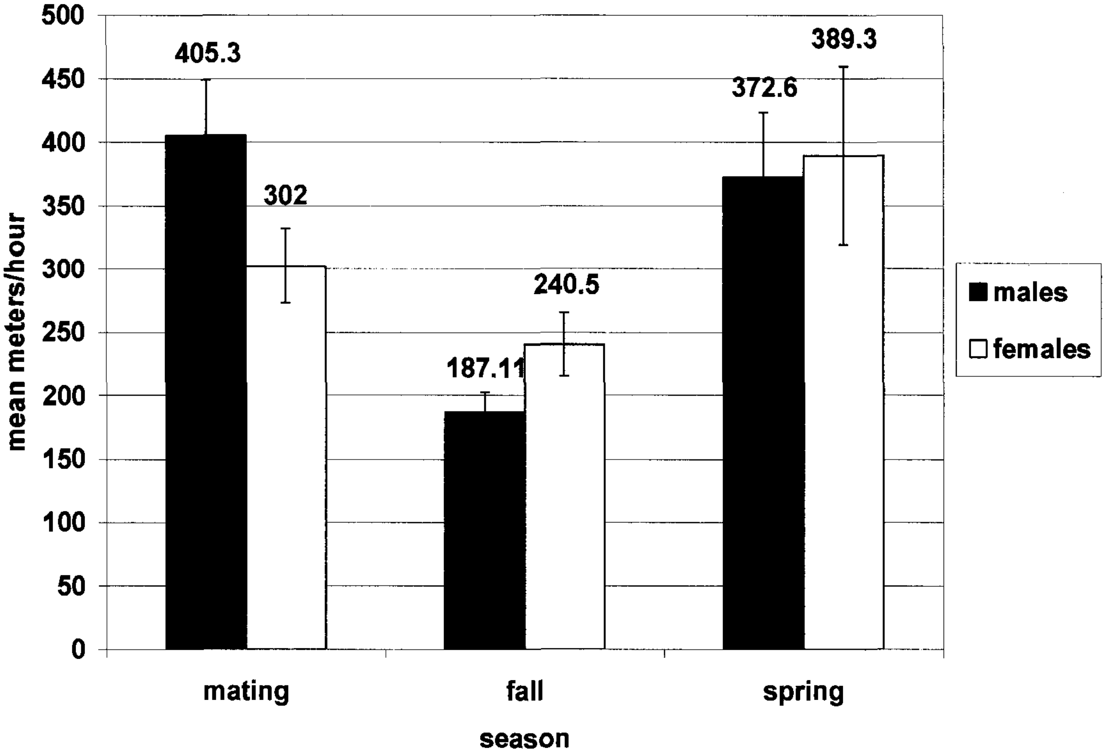

Figure 2.5: Average travel speeds moved (meters/hour) by American badgers; for each sex during each season. Histogram bars are labeled with mean values and standard error.

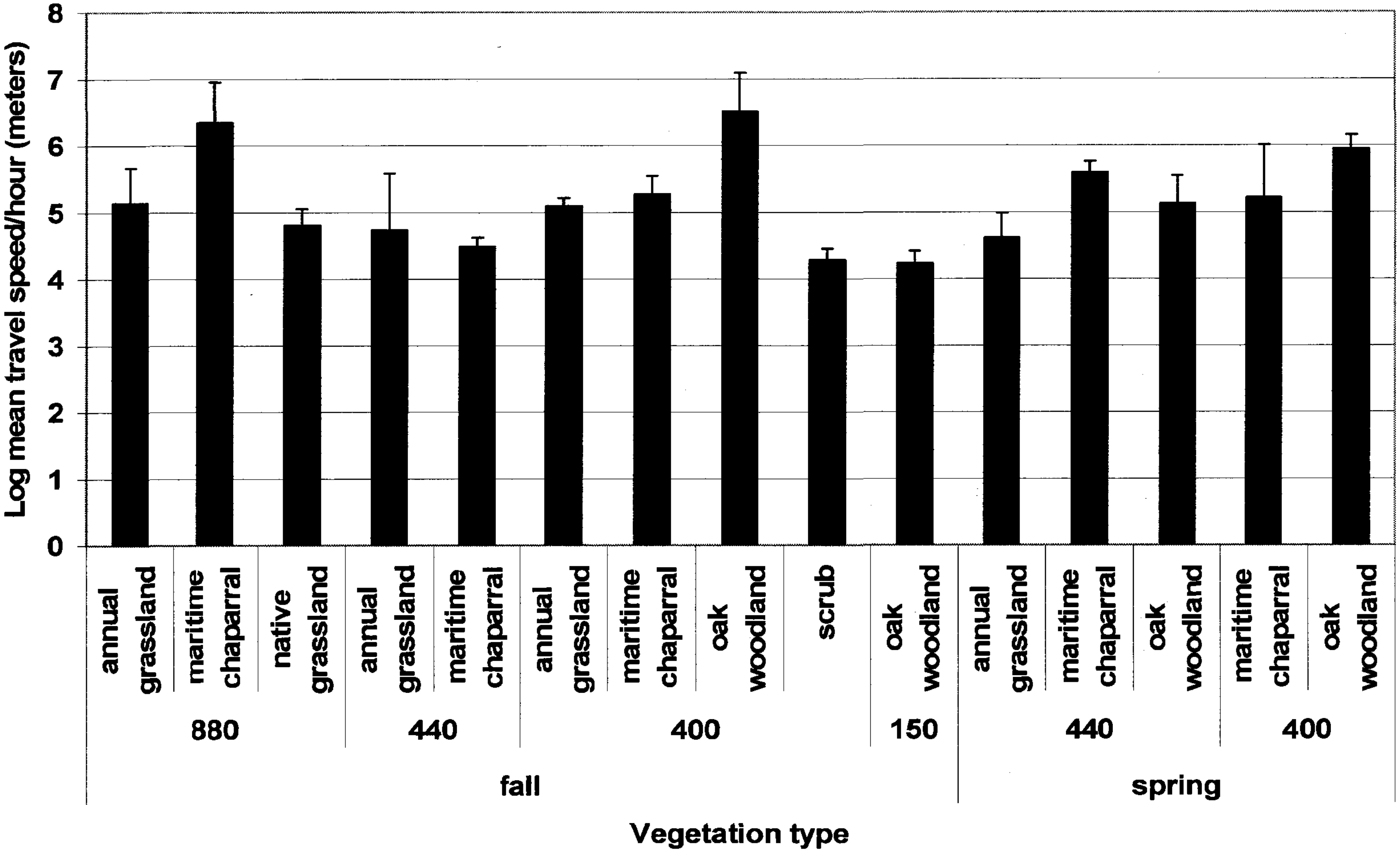

Figure 2.6: Average travel speeds moved (log meters/hour) by individual male American badgers (labeled by the last three digits of their radio frequency) through vegetation type during seasons where travel speeds between the vegetation types differed significantly.

The stepwise selection procedure retained only dominant vegetation types when classed in two groups (annual grassland & oak woodland / maritime chaparral & native grassland & scrub), in determining the effect of vegetation type on path tortuosity in the sessions. In an ANOVA using this model, a weak effect of vegetation on path tortuosity was detected; travel paths were slightly more tortuous (complex) in maritime chaparral, native grassland, and scrub habitats than in annual grassland and oak habitats ($F_{1, 59} = 3.82$, $P = 0.06$).

DISCUSSION

As expected, both sexes exhibited lower travel speeds during the months of October, November and December compared with the rest of the year. While not true hibernators, badgers do enter periods of inactivity, and even bouts of torpor, in the winter. This has been documented primarily in areas with very cold, snowy winters (Sargeant & Warner 1972, Lindzey 1978, Harlow 1981, Hoodicoff 2003). As the winter temperatures on the central coast of California are mild, badgers may have reduced their activity more in response to a reduction in prey activity levels rather than temperature. Gophers' activity rates decline through dry periods (Romañach *et al.* 2005), and thus would be at a minimum just prior to the winter rains (in this study site, rains typically start in January). Where badgers primarily prey on California ground squirrels, their activity levels outside their breeding season may be reduced anytime between July and December, when ground squirrels enter torpor (Dobson & Davis 1986).

It is interesting to note that females' travel speeds were higher than males' during fall, albeit not significantly so. Fat reserves built up in the fall and winter are important for breeding females (Harlow *et al.* 1985). The energetic requirements for gestation in badgers are markedly lower than those of most other carnivore species; thus the growth and development of the fetuses is not affected even if a pregnant badger fasts during torpor (Harlow *et al.* 1985). Lactation, conversely, is about 4 times as energetically costly for badgers than for other species, and about 16 times more energetically costly than gestation. Thus, maintaining adequate fat reserves through the winter to support lactation in early spring is likely to be critical for kit survival (Harlow *et al.* 1985). Female badgers, more than males, may then be expected to increase their movements or hunting efforts during this time of fall/winter fattening. The females observed during the fall of this study were not tracked through the following spring, so it is unknown whether or not they were preparing for birthing young.

Increased rates of movement in the mating season as well as in the spring may have been a response to both increased prey activity (spring) and breeding activity. During the spring, both sexes may be replenishing weight that is lost during the relatively inactive winter months. However, as both sexes increased their activity levels during the mating season (rather than just the males, which would be expected), perhaps a combination of prey availability and mating behavior played a role in affecting movement during that season. It is also possible that females, as well as males, increase their movement to actively pursue mating opportunities, as was observed in European badgers (*Meles meles*) (Woodroffe *et al.* 1995).

Considering variations in travel speeds to be an indication of habitat selectivity, only male badgers exhibited preference based on vegetation type in their movement paths. More specifically, males were selective of habitat type in all seasons except the mating season. As the rates of movement in the mating season did not differ significantly from movement rates in the spring, it is likely that habitat selectivity was not just diminished when movement rates increased. Alternatively, the factors driving the increased rate of movement were probably different across the two seasons resulting in different patterns of habitat selection. Thus, when males are moving more while searching for mates, they are less selective of habitat type as it does not necessarily reflect the distribution of their primary resource (females). However, when not actively searching for mates, males may be moving more in response to the distribution of food resources, which are habitat-dependent. It seems that the same pattern should hold for females, whose movements may be dictated by resources rather than mates year-round (Minta 1993, Goodrich & Buskirk 1998). Females in this study; however, did not vary their movement rates in response to vegetation. Perhaps this is because females had already situated their home ranges within preferred habitat at the larger scale, while the home ranges of males, which are larger, included more unfavorable habitat types. Again, females may have actively been looking for mates as well (Woodroffe *et al.* 1995).

While habitat preference was evident in males, individual variation in which habitats were preferred obscured any general patterns of habitat selection in the badgers observed in this study. Similarly, studies by Hoff (1998) and Hoodicoff (2003) found that even though individual animals preferred certain habitat types over others, the pattern of selection was not consistent across animals. As badgers are opportunistic in their foraging habits, and tend to adjust their diet based on resource availability (Jense 1968, Sovada *et al.* 1999), this result probably reflects not only the variation in individual preferences, but also the variation in the availability of resources encountered by each animal between seasons, or even during a single tracking session. Conversely, as has been observed in other badger studies, individual animals in this study may have learned to somewhat specialize in a single type of prey or a certain hunting strategy; such individual specialization may have been different across individuals (Hoodicoff 2003). Such variation has also been observed in sea otters (*Enhydra lutris*), another mustelid (Estes *et al.* 2003). For example, one male badger in this study (151.440) was observed to regularly dig up wood rat lodges, which occurred most often in oak woodland habitat. This behavior was not observed in other animals.

Path complexity varied only slightly between the vegetation types in this study, with more complex paths being observed in scrub, maritime chaparral and native grassland habitat than in oak woodlands or grasslands. However, badgers spent a great deal of their time in annual grasslands, and have been observed to associate with both annual grasslands and oak woodlands at larger spatial scales (Chapter 1). If increased path complexity reflects higher preference, finding that badgers travel in straighter paths in these habitats is unexpected. Conversely, in scrub habitat, which was preferred at the study site scale as well as within the home range for den placement (Chapter 1), badgers moved in more complex paths. It may be possible that the complexity of badger movement paths does not reflect feeding habitat preference alone. Path complexity may also be a result of individual navigation strategies for seeking mates or finding dens, and thus would not be consistent across animals or other external factors. Moreover, as mentioned above, individual variation in habitat preferences may supersede a general relationship of path complexity to specific habitat types across individuals. Finally, physical structures such as terrain or the presence of dense vegetation, not explicitly quantified here, may be important influences on path complexity.

The small sample size of animals obtained for this study necessitates caution in extrapolating results, especially to badger populations in other habitat types. However, the patterns of badger movement exhibited here may be important to consider in conservation plans that use badgers as a focal species (sensu Lambeck 1997). Any assessment of animal movement between protected areas or habitat fragments should optimally be conducted during the periods of highest movement; in California that would be during the spring and during the breeding season, as both sexes increased their movement rates during those time periods. For example, male badgers were selective of habitat during the spring, and perhaps may be more apt to use corridors of higher quality habitat during that time. At the same time, they might be less likely to leave core habitat in the spring if it is surrounded by an unfavorable landscape matrix, such as human development. In the mating season; however, as males were less selective for habitat, they may be more willing to leave core habitat. Yet this increased movement may be costly if they tend to move through more marginal or dangerous habitat types than they do in the rest of the year. Females, on the other hand, did not seem to be selective of habitat in their movement paths year round, as indicated by their similar movement rates in different habitat types. Such behavior might indicate that females too are susceptible to a high cost of movement that could result from using less favorable habitats, and could be particularly sensitive to habitat fragmentation.

A lack of habitat selection in badgers while they are traveling long distances would be particularly concerning if they tended to use human-modified landscapes. Unfortunately, too few badgers in this study ventured into the residential and agricultural areas adjacent to Fort Ord during the tracking sessions to adequately assess selection for or against these habitat types, as well as the extent to which season or sex affected this behavior. In fact, only one badger (a male) was observed crossing a major road and using a residential area during the course of this study, though not during any of the sessions considered in this analysis. However, other studies have indicated that badgers are highly susceptible to vehicle collisions on roads, and road-killed badgers have been observed to increase in frequency in the late summer (Messick & Hornocker 1981, Hoodicoff 2003). Moreover, badgers are often killed due to conflicts with humans in both agricultural and residential areas (Minta & Marsh 1998, Quinn & Diamond *in prep*). While a further understanding of badger movement through marginal habitats, as well the demographic impacts of mortality in those habitats is important; maintaining large and connected habitat for badgers to move through is also likely be critical to managing their populations locally in the short term.

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CHAPTER 3

INVESTIGATING CHANGES IN THE RANGE EXTENT OF AMERICAN BADGERS IN CALIFORNIA (*TAXIDEA TAXUS*) USING SIGHTINGS DATA.

Abstract

The American badger (*Taxidea taxus*) is currently listed as a Species of Special Concern in California, as the population is thought to have declined since the mid-1880s. I used available sightings data to identify environmental factors affecting the current population distribution of American badgers in California. I also examined factors that may be associated with declines in badger occurrences over the past 50 years. Analyses were conducted by ecoregion (defined by broad patterns in vegetation, climate, topography, and geology across the state). Environmental features associated with badger occurrences and declines varied by ecoregion. While an association with grasslands and shrub cover was detected in some ecoregions, an association with forest and woodland habitat was detected in others. In remote ecoregions, human-altered habitats (percent agricultural vegetation and road density) were positively associated with badger occurrences. Declines in badger occurrences were associated with human-altered landscapes in two ecoregions. Using sightings data to predict badger occurrences and declines was generally unreliable. Only between 16% and 75.8% of modern occurrences were correctly classified, and up to 64% of losses in sighting occurrences were correctly classified. While opportunistically-collected occurrence data may be the only data available for population assessments of a species at very large scales, their utility in predicting presence or assessing changes in population distribution may be limited unless coupled with systematic sampling.

INTRODUCTION

For rare or elusive carnivore species, large-scale population assessments can be difficult to conduct. A primary challenge to such an assessment is establishing baseline data on population distribution and abundance. Rigorous surveys at large scales (i.e. > 10,000 km^2) are only rarely conducted; although regional programs exist for fishers (*Martes pennanti*), martens (*Martes americana*), and wolverines (*Gulo gulo*) in California (eg. Carroll *et al.* 1999, Campbell 2004). In some cases, if there is a known close association between a species and a specific habitat type, that species' presence at a site can be inferred if that habitat is present. However, for generalist or wide-ranging carnivores, whose presence or absence may depend on multiple factors, including human-caused factors (such as predator control or hunting), habitat-based conclusions alone may not be sufficient. Many carnivores have broad habitat requirements that may even vary by region, requiring definite occurrence data to fully analyze correlates of population distribution (Carroll *et al.* 2001).

In some cases, the only data available for evaluating large scale population patterns are trapping records, sighting records, or museum specimens. Such data can sometimes be problematic for fine-scale analysis due to the inherent bias of opportunistically collected data, and potential observer uncertainty or error. However, if data are screened *a priori*, they can be appropriate for assessments at the large scale (Stoms *et al.* 1993). In several cases, sightings data have been used to construct coarse habitat models (Palma *et al.* 1996, Carroll *et al.* 2001, Livatis *et al.* 2006), or to make comparisons of species' range extents across several time periods (Rodriguez & Delibes 2002, Rodriguez & Delibes 2003).

Here, I investigated the distribution of the American badger (*Taxidea taxus*) in California, U.S.A. The American badger is a medium-sized carnivore uniquely adapted to maintain a semi-fossorial lifestyle (Long 1973). On a landscape scale, badgers are usually associated with grasslands and early successional stages of other habitat types (Apps *et al.* 2002, Hoodicoff 2003, Chapter 1). Historical records indicate a potentially widespread range throughout California. Grinnell *et al.* (1937) report that the American badger was common across the state in the mid-1800s through early 1900s, with centers of abundance in the valleys and hills of the Coast ranges, in the uncultivated rolling hills and margins of the Great Valley, on the Great Basin Plateau, and in high mountain meadows and plateaus of the Sierra. From the late 1800s through early 1920s, however, badgers were trapped for their pelts. Anecdotal reports and trapping records suggest that their numbers declined as much as 90% during this time (Grinnell *et al.* 1937). In the late 1980s, surveys of licensed trappers throughout the state that spanned a much larger time period than did previous surveys yielded more sightings overall; however, in certain areas, sighting frequency seemed to have declined (Larsen 1987). As a range contraction was suspected, the badger was listed as a Species of Special Concern in California (defined as taxa in California that lacked a listing status of Threatened, Endangered, or Fully Protected; yet still seemed vulnerable to extinction) by the California Department of Fish and Game (CDFG) in 1986. The initial conservation assessment that resulted in this listing status also acknowledged a general lack of data regarding badgers in the state (Williams 1986). Badgers are currently considered "uncommon" throughout their range by CDFG. Moreover, because of their secretive habits (solitary, nocturnal, and fossorial behavior), badgers are likely under-detected where they occur.

The threats to badger populations in California have not been established conclusively, but based on badger ecology and studies conducted in other states, they are likely varied. In California and elsewhere, studies suggest that, as wide-ranging animals (home ranges as reported in the literature are from 1.6 – 65 km^2 for females and 2.4 – 541 km^2 for males [Chapter 1]), badgers are extremely sensitive to the effects of habitat loss and fragmentation (Hoodicoff 2002, Crooks 2002). In urbanizing areas, badgers may be very susceptible to mortality from vehicle collisions on roads due to their poor vision, nocturnal habits, and tendency to travel by olfactory cues (Messick *et al.* 1981, Minta 1993, Hoodicoff 2003). Where natural habitats are converted to agriculture, badgers may suffer losses in prey base due to large-scale rodent control efforts (Minta & Marsh 1988); or may be susceptible to secondary poisoning from anticoagulant rodenticides (Quinn *et al. in prep*). While trapping for pelts has decreased significantly since the early 1980's, badger populations are still lethally controlled due to damage incurred from their extensive digging in agricultural fields, rangelands, and suburban areas, (Minta & Marsh 1988). The level of control for damage management is not clearly known, but occurs at high levels in some areas (Quinn & Diamond *in prep*).

The true effects of these threats on badger populations are unknown. Declines in badger populations have never been assessed quantitatively in California; nor have spatio-temporal patterns in the population distribution. However, these data are needed to inform conservation planning priorities throughout the state. The objective of this study was to use available occurrence data to assess the population status of badgers in California as part of a statewide conservation assessment. First, I examined the factors associated with the modern (later than 1965) distribution of badger occurrences in

California. Second, I compared the distribution of modern badger occurrences to the distribution of historic badger occurrences, and analyzed factors associated with losses in sighting occurrences between the two time periods.

METHODS

The study area encompassed the entire state of California, which has a land area of over 423,000 km^2 and is located along the western coast of North America. The landscape within the state boundaries is diverse; with elevations ranging from 86 m below sea level in Death Valley, to 4,418 m in the Sierra Nevada Mountains. The northwestern coast of the state is characterized by cool, wet conditions and temperate rainforest; transitioning to a Mediterranean climate on the central and southern coast, with dry, warm summers and rainy winters. The north and central coastal regions extend eastward to north-south coastal mountain ranges, east of which lies a long, low-elevation valley. To the east of the valley, the Sierra Nevada and Cascade mountain ranges are cooler and drier, with deep winter snow packs. Desert regions lie to the east of those mountain ranges, in their rain shadow. Both north-south and east-west mountain ranges lie to the east of the southern coast; likewise deserts extend east in the rain shadow of these ranges.

Habitat throughout the state is as varied as the topography, including grassland prairies in the valleys and foothills, oak woodlands and forests in coastal ranges and foothills, conifer forests with alpine meadows in the higher elevation mountain ranges; and chaparral, shrublands, and desert shrublands in the drier regions of the state. California is a populous state, home to over 36 million people (United States Census

Bureau 2006). Human population is concentrated in the Bay Area on the central coast, the cities of Los Angeles and San Diego on the southern coast, and a few major cities in the central valley. Suburban and low-density residential areas typically extend for miles beyond urban areas. Inland desert regions in the southern portion of the state are also quickly growing to become major population centers. Much of the low elevation habitat in the Central Valley has been converted to agriculture (Fig. 3.1).

Badger occurrence data

I first consolidated existing occurrence reports for badgers in California from multiple sources. For historical occurrences, I included locations of animals trapped between 1919 and 1927 (Grinnell *et al.* 1937) as well as locations of museum specimens collected during the same time period (including those listed in Williams [1986]). For modern occurrences, I used badger locations reported by licensed trappers and agency personnel throughout the state in a 1986 survey, which dated back as early as 1965 (Larsen 1987). Additional occurrences (through January 2007) were collected from sightings recorded in the California Natural Diversity Database (CNDDB). I collected additional sighting locations through telephone and email surveys targeting agricultural commissioners, county trappers, agency biologists, and members of the general public in 2003 and 2004. Finally, I added locations of recent (post-1985) museum specimens to the list of badger location data.

The quality of the sightings reports varied. Thus, all occurrences were assigned a radius of precision based on the description of the sighting location and place name, combined with visual inspection of topographic maps and aerial photographs.

Occurrences with a precision of less than a 200 km^2 area were excluded from further analysis. Locations were then digitized as point data in a geographical information system (GIS). Occurrences were classified by the time period during which they occurred: modern or historic. Historic occurrences were considered those that occurred prior to 1965; modern were considered those that occurred during and after 1965. The year 1965 was chosen as the cutoff as it was the earliest sighting included in the CDFG survey data (Larsen 1987); it also correlated with the beginning of a period of rapid human population growth in California, as determined by examining United States Census Bureau data (Fig. 3.2). To somewhat reduce the effect of clusters of occurrences due to unequal sampling effort (i.e. multiple reports from a single observer), and to encompass the area of precision around each occurrence, I generated a grid of 20 km x 20 km cells covering the entire state. For each time period (modern or historical), cells were classified as containing a badger occurrence (coded as "1") or not containing an occurrence (coded as "0").

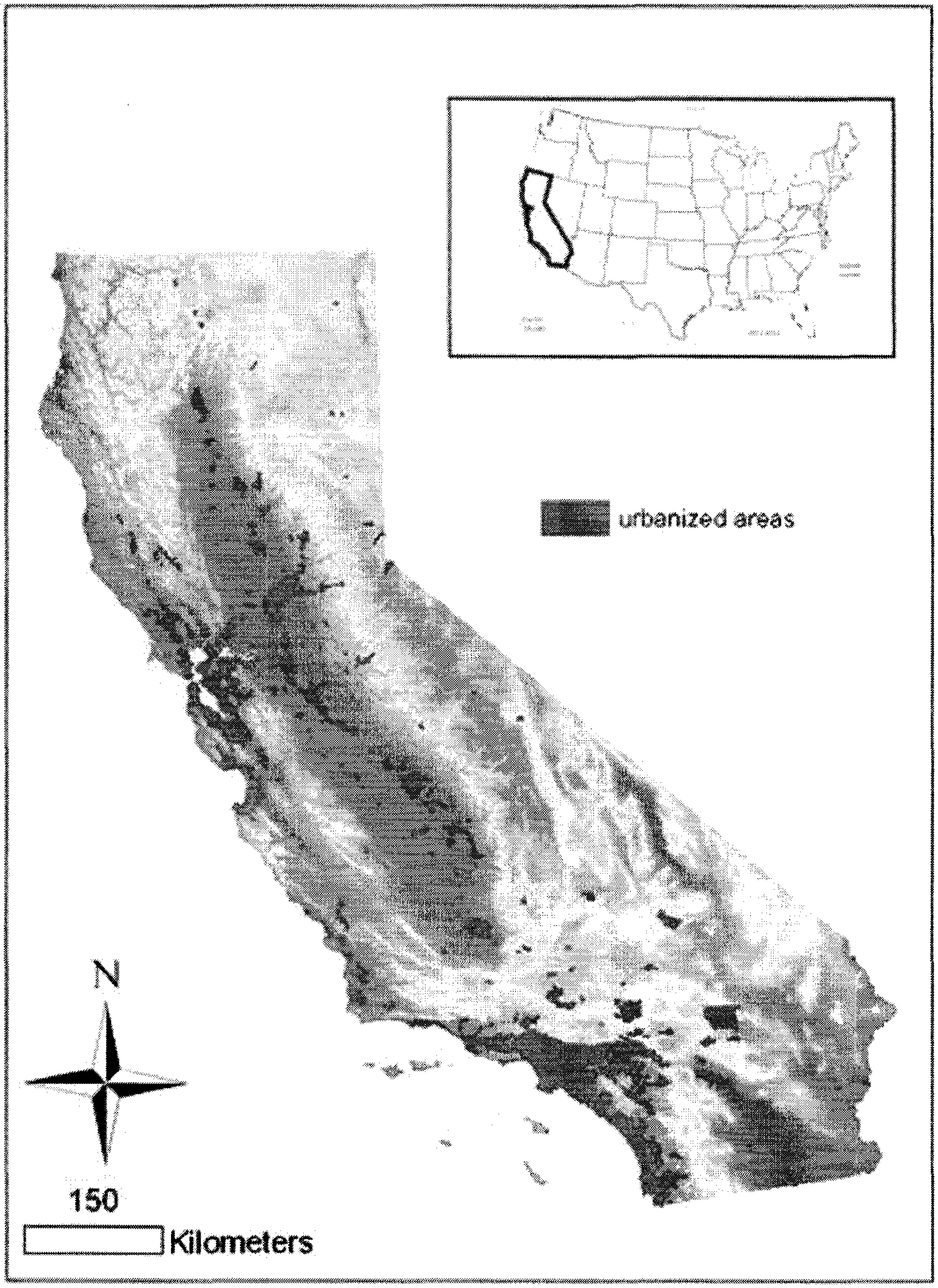

Figure 3.1: Relief map of the study area, California, USA. Urban areas are shaded in gray.

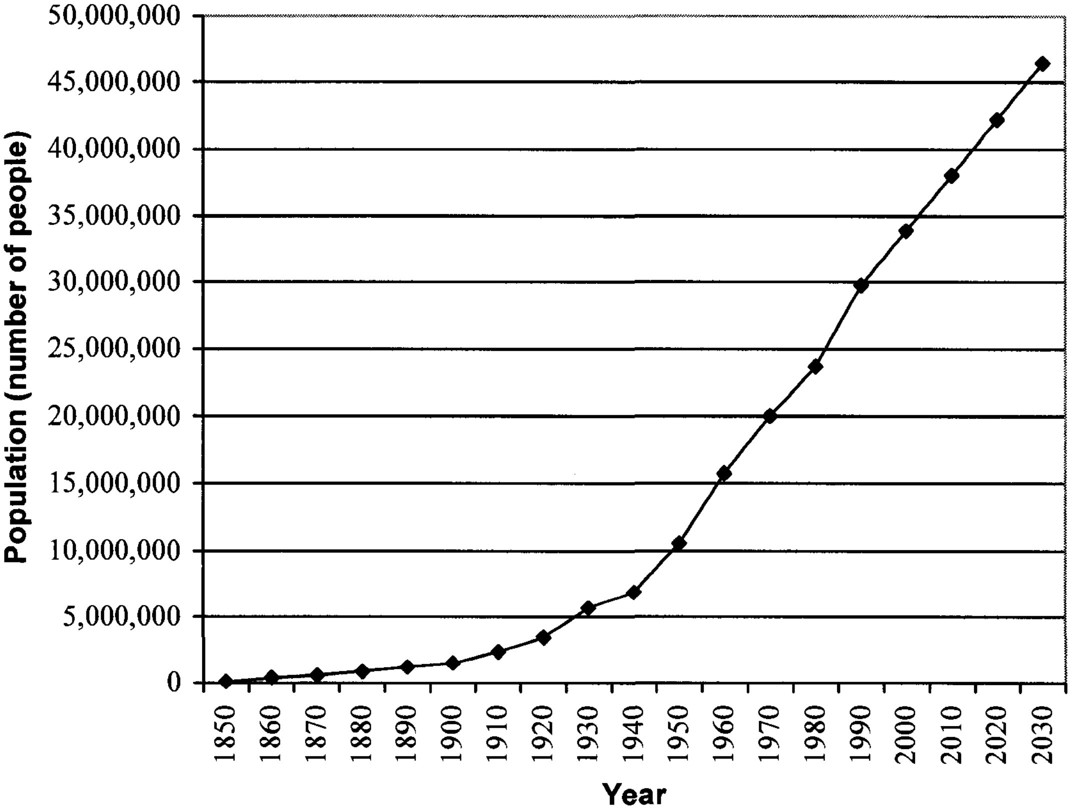

Figure 3.2: Population growth in California, 1850—2030 (2006—2030 projected growth; United State Census Bureau Data).

GIS layers from various sources were used to classify each grid cell by habitat characteristics (Table 3.1). Vegetation data were obtained from the California Department of Foresty Resource Assessment Program's Multi-source land cover data. This raster dataset compiles the best available vegetation data from several sources statewide, combining them into a single raster layer with a resolution of 100 meters. Vegetation types were classified according the California Wildlife Habitat Relationship (CWHR) system classification, then reclassified into 13 broad land cover subclasses, which I used in this analysis. Elevation data from the CON500 layer in the California Spatial Information Library were used to describe topography. This layer was created by merging together United States Geological Survey (USGS) 1-arc second digital elevation models (DEM) spanning the entire state. The composite of the DEMs was then classified into 500-foot elevation classes and resampled from 30 meter to a 90 meter cell size, and converted to a polygon coverage. I converted the polygon layer to a raster layer for this analysis, with a cell size of 100 meters.

Because of the sheer size and diversity of the area covered by the data, I performed analyses by ecoregion. Further, I expected the factors affecting occurrence distribution would be partially specific to the landscape variation that the ecoregions described, making an ecoregional assessment more accurate A polygon layer delineating the Jepson ecoregional boundaries was obtained from California GAP Analysis data (Fig. 3.3). These ten ecoregion divisions were developed for characterizing the occurrence of plant species and communities throughout California in Hickman (1993).

Table 3.1: Data layers used in analysis of habitat associations of badger occurrences in Calfornia.

Data layer	Resolution	Categories	Source
Land cover	100 m	% Herbaceous % Agriculture % Hardwood forest % Hardwood woodland % Conifer forest % Conifer woodland % Shrubland % Desert shrubland % Desert woodland % Water % Wetland % Urban % Barren	California Department of Forestry; California Wildlife Habitat Relationship Classification System
Elevation	90 m	Average elevation (range: 0-9815.0 m)	United States Geologic Survey; California Spatial Information Library
Terrain diversity	90 m	Number of 500-m elevation classes (range: 1-21)	United States Geologic Survey; California Spatial Information Library
Roads	1:100,000	Road density (linear km/km^2, range:)	California Department of Transportation
Ecoregion	1:100,000	Northwest Cascade Modoc Central West Great Valley Sierra Nevada Eastern Sierra Nevada Southwest Mojave Desert Sonora Desert	Davis *et al.* (1998), Hickman (1993)

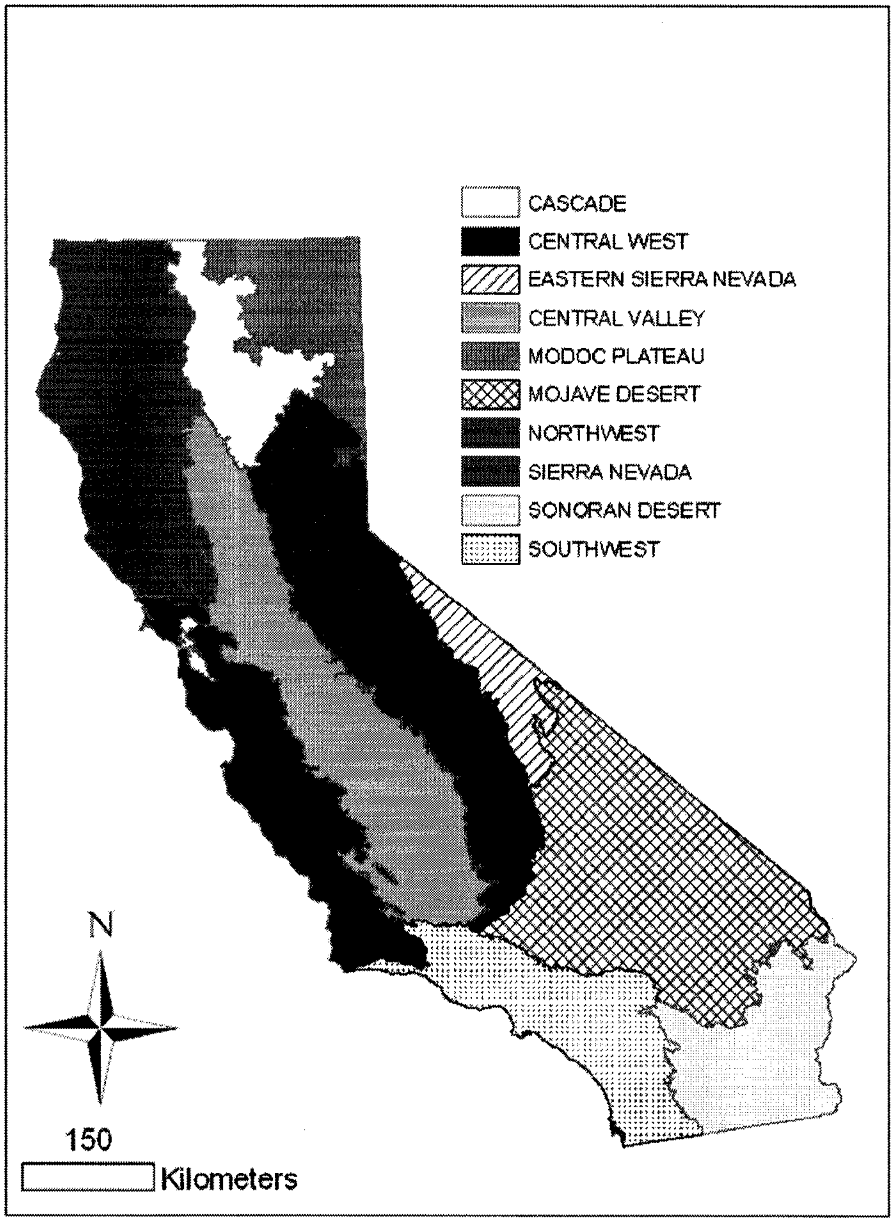

Figure 3.3: Jepson ecoregion boundaries (Hickman 1993).

The regions were qualitatively defined by variation in natural landscape features, including broad vegetation types, geology, topography, and climatic conditions. The Northwest ecoregion includes the wet, forested, northwestern part of the state from the coast to the Klamath Mountains. The Modoc ecoregion encompasses the Modoc plateau, which is characterized by the high-elevation Great Basin deserts east of the Cascade Mountains. South of the Modoc ecoregion, the Cascade ecoregion includes the conifer forests of the Cascade Mountains, as well as oak woodland foothills to the west. The Central West ecoregion is located to the south of the Northwest ecoregion, and includes the coastal grasslands and dunes, as well as the oak woodland foothills and conifer forest of the coastal ranges. The Great Valley ecoregion runs north to south down the center of the state, and is comprised of extensive flat grasslands, river drainages and wetlands, bordered by oak woodland and chaparral foothills on either side. The rugged Sierra Nevada ecoregion includes the high alpine forest and tundra of the Sierra Nevada Mountains, and the oak woodlands, chaparral, and piñon-juniper foothills on the western flanks. The Eastern Sierra Nevada ecoregion contains the high elevation Great Basin desert scrub and grasslands in the rain shadow of the Sierras.

In the southern part of the state, on the eastern side of the southern edge of the Sierras, the expansive Mojave ecoregion is characterized by varied topography and desert habitat, ranging from desert scrub on high plateaus to dry conifer forests in mountain ranges. On the southern coast, the Southwest ecosystem contains diverse coastal habitats of grasslands, coastal sage scrub and chaparral. Chaparral and oak woodland habitat ascend into rugged mountain ranges of conifer forests, with arid deserts on the eastern sides. The Sonoran Desert ecoregion lies to the east of the southern mountain ranges, and is relatively low-elevation desert scrub and desert woodland habitat. Dry and warm most of the year, the Sonoran Desert receives rains in the winter and late summer. Accordingly, some socio-economic variations may also be encompassed by these delineations; such as agricultural practices, suburban/urban development patterns, human population density, as well as patterns of species declines and conservation threats (Seabloom & Dobson 1999, Bunn *et al.* 2007).

Each grid cell was characterized by habitat characteristics that occurred within its boundaries, as determined by overlapping the grid cells on the other layers. Because all layers were clipped to the extent of the state boundary, in cases where the grid cel's overlapped the state boundary, only the portion falling within that state boundary was considered. Thus the total area of a grid cell crossing the boundary was smaller than one which fell entirely within. I calculated the percent composition of each land cover type and the area-weighted mean elevation of each grid cell. I calculated an index of terrain diversity for each cell, defined as the number of elevation classes contained within each grid cell.

Roads data were obtained from the California Department of Transportation functionally classified roads layer in a vector format. Road density was calculated by totaling the linear kilometers of road that occurred within each grid cell and dividing by the area of that cell. Finally, grid cells were classified by the Jepson ecoregion within which they were located. When grid cells crossed ecoregional boundaries, they were classified as the one in which over half of that cell was located.

Distribution of modern badger sightings (1965-2007)

Analysis of factors associated with the distribution of badger sightings was only conducted for modern occurrences, since GIS data layers available for analyses were based on recent landscape survey data. I also minimized the number of variables considered in model-building by screening them *a priori*. I first performed univariate analyses, comparing the habitat characteristics of grid cells containing a badger occurrence to those without an occurrence using a Wilcoxon rank sum test. Only variables that differed between the two at a value of $P < 0.10$ in univariate tests were retained for further analyses. Using these selected variables, I constructed a correlation matrix to identify redundant variables and to reduce potential collinearity. Of any correlated pair ($r>0.7$), the variable with a lower P value in univariate analysis was excluded. For each time period within each ecoregion, the effect of remaining variables on badger occurrence within a cell was then analyzed used logistic regression. A forward stepwise selection procedure using a threshold alpha level of 0.25 to enter the model and 0.10 to leave was used to construct the final model. The final model was run as a logistic regression analysis determining the effect of predictor variables on badger occurrence, assessed at an alpha level of <0.05. In cases where observations were too sparse to estimate some parameters of the model, variables that resulted in unstable parameter estimates were removed from the model.

Classification accuracy of the models was assessed by determining the percentage of cells correctly classified as having badgers occurrences either present or absent.

Comparison of modern and historic data

For this analysis, I considered grid cells in which a badger occurrence was recorded during either time period. Cells that had a historical occurrence but no modern occurrences were classified as a loss (coded as “1”); those with historical occurrences *and* modern occurrences, or just modern occurrences, were classified as a presence (coded as “0”). Variables were pre-screened for inclusion in the same fashion as the previous analyses.

RESULTS

A total of 938 occurrence records were considered in the final analysis, consisting of 373 historic occurrences (dating from 1965 or earlier) and 565 modern occurrences (dating after 1965). Of those, 236 were museum specimens, 183 were sightings reported during email and phone surveys (2003-2004) or to the CNDDB, 314 were sightings reported in Larsen (1987), and 206 were historic trapping records mapped by Grinnell *et al.* (1937). The 20 km x 20 km grid layer included 1,134 cells covering the state. When overlain with the badger occurrence point locations, 332 grid cells contained modern occurrences, and 232 contained historic occurrences. Eighty-six (86) cells contained sightings for both time periods, and 657 cells contained no occurrences for either time period (Fig. 3.4). All 10 ecoregions contained badger occurrences; however, the Eastern Sierras contained only 7 historic records and 5 modern records, and thus this ecoregion was excluded from further analyses due to the small sample size.

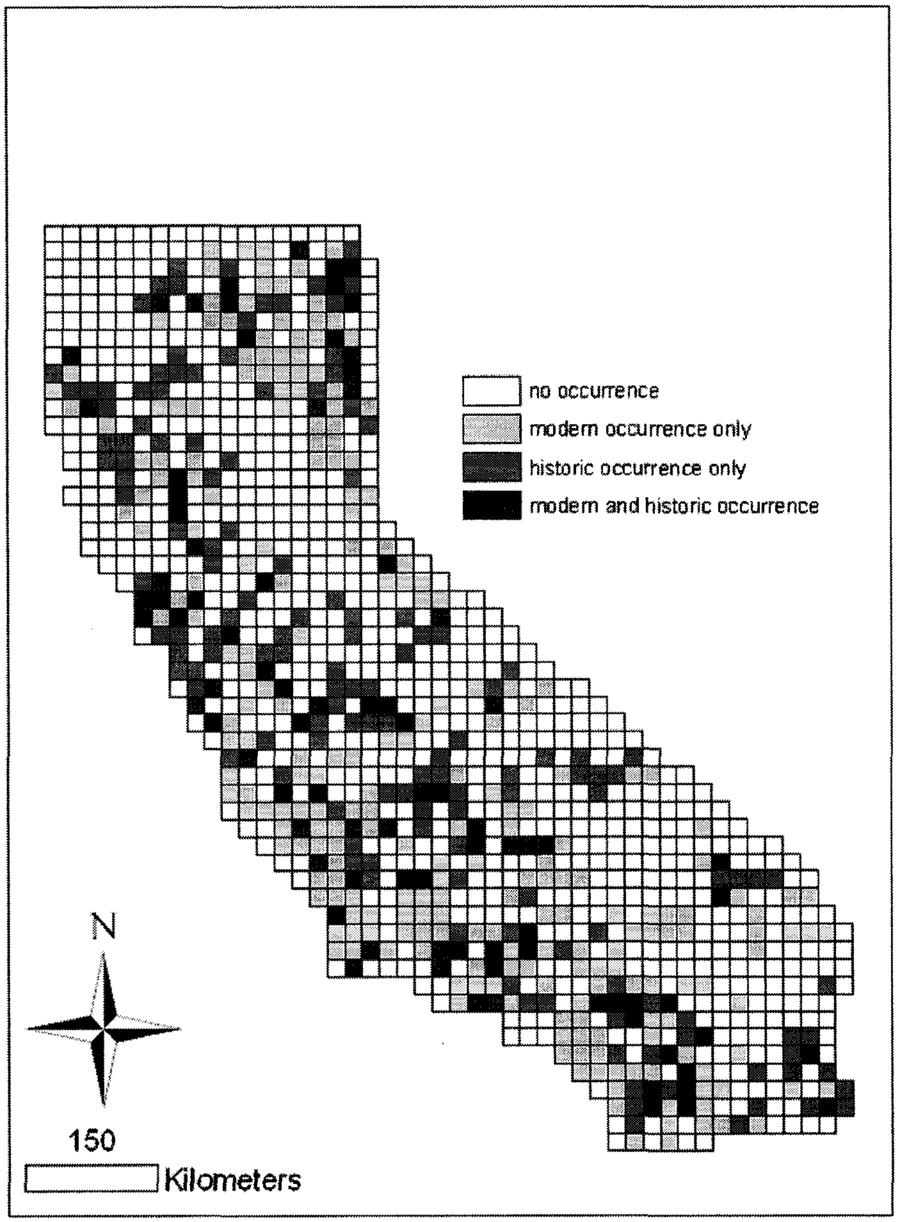

Figure 3.4: Historic (before 1965) and modern (after 1965) American badger (*Taxidea taxus*) occurrences; as recorded in trapping records, museum records, and sighting reports; in 20-km grid cells across California

Distribution of current badger sightings

Univariate analysis showed differences at the 0.10 level in 3 to10 habitat variables per ecoregion in cells containing badger occurrences and those that did not. Predictors of occurrence were not always consistent across ecoregions; however (Table 3.2). A consistently positive association in more than one ecoregion was found with average elevation and road density; i.e. badgers were more likely to be recorded at high elevations and high road densities. In several ecoregions, badgers were also more likely to be sighting at locations with high percent coverage of conifer woodland, shrub, water, barren, herbaceous or desert woodland habitats. A positive association with percent coverage of agriculture was detected in 6 ecoregions; although the association in the Great Valley was negative. After variable screening and stepwise regression, only between two to four variables remained in final models per ecoregion; these varied amongst the ecoregions. Classification accuracy of the resulting logistic regression models also varied across ecoregions. In many cases, the models more accurately predicted absence rather than presence, the Central West ecoregion being the exception (Table 3.3).

Table 3.2: Univariate relationships between badger occurrences and habitat variables, as determined by Wilcoxon Rank Sum tests. Sign indicates the direction of the relationship; significance of relationship is indicated as follows: $P < 0.1$ (+/-), $P < 0.05$ (++/--), $P < 0.001$ (+++/---).

Variable	Cascade	Central West	Modoc	Mojave	Northwest
Average elevation	+++				
Terrain diversity			+	-	
Road density			+++	+++	++
% Agriculture	++	++	+	+++	++
% Hardwood woodland	---	++		+	+++
% Hardwood forest	---			++	
% Conifer forest	++				---
% Conifer woodland					
% Shrub					
% Water	+			++	
% Wetland	++				
% Barren	+	++			
% Urban				+++	
% Herbaceous				+	+++
% Desert shrub				-	
% Desert woodland				+	

Table 3.2 (cont.): Univariate relationships between badger occurrences and habitat variables, as determined by Wilcoxon Rank Sum tests. Sign indicates the direction of the relationship; significance of relationship is indicated as follows: $P < 0.1$ (+/-), $P < 0.05$ (++/--), $P < 0.001$ (+++/---).

Variable	Sierra	Sonora	Southwest	Great Valley
Average elevation				+++
Terrain diversity		++		++
Road density				
% Agriculture	++			− −
% Hardwood woodland		+++		
% Hardwood forest	− − −	++	−	− −
% Conifer forest		++		
% Conifer woodland	+++	+++		+
% Shrub	++	+++		
% Water				
% Wetland		+++		− − −
% Barren		+++	+	
% Urban				
% Herbaceous		+++	++	+++
% Desert shrub	++			++
% Desert woodland	+			

Table 3.3: Variables contained in multiple logistic regression models for presence of modern badger sightings; showing coefficients, standard errors, and significance values.

Ecoregion	Variable	Coefficient	1 SE	χ^2	*P*	Occurrences correctly classified (% of presences/ % of absences)
Cascade	Intercept	-5.834	1.655	12.43	<0.001	66.7 / 80.0
	Average elevation	0.001	0.001	6.97	0.008	
	% Water	0.136	0.082	2.73	0.098	
Central West	Intercept	-0.697	0.365	3.64	0.057	75.8 / 58.8
	% Agriculture	0.041	0.019	4.60	0.032	
	% Hardwood woodland	0.033	0.014	5.51	0.019	
Modoc	Intercept	-1.615	0.657	6.05	0.014	58.6 / 85.7
	Road density	0.022	0.010	4.87	0.027	
Mojave	Intercept	-4.620	1.890	6.00	0.014	20.0 / 98.1
	Road density	0.011	0.003	11.10	<0.001	
Northwest	Intercept	-0.609	0.573	1.13	0.288	16.0 / 97.7
	Road density	0.014	0.007	4.34	0.037	
	% Agriculture	-0.116	0.066	3.07	0.080	
	% Conifer forest	-0.035	0.010	12.43	<0.001	
Sierra	Intercept	-0.763	0.360	4.49	0.034	13.9 / 96.1
	% Hardwood forest	-0.233	0.075	9.76	0.002	
Sonora	Intercept	-1.642	0.320	26.41	<0.001	31.6 / 98.4
	% Shrub	0.331	0.146	5.15	0.023	
Southwest	Intercept	-0.705	0.370	3.62	0.057	66.7 / 61.7
	% Herbaceous	0.093	0.042	5.01	0.025	
Great Valley	Intercept	-1.425	0.395	12.98	<0.001	23.7 / 98.2
	% Herbaceous	0.028	0.010	7.32	0.007	
	% Desert shrub	0.464	0.181	6.55	0.011	

Comparison of recent and historical data

Sightings for modern and/or historical time periods occurred in 466 grid cells. Losses (occurrences in historical data, but not modern) occurred in 30% of those cells

(141 cells; see Fig. 3.3). In univariate analyses, differences in cells containing a loss in badger occurrences between historic and modern times compared to those containing a presence were detected for up to 6 variables per ecoregion. Again, relationships between habitat variables were not necessarily consistent across the ecoregions. In the Modoc ecoregion, no differences in any of the predictor variables were detected. Losses were positively associated with average elevation across two ecoregions (i.e. losses were more likely at high elevations), and were negatively associated with average elevation in one ecoregion. Similarly, losses were positively associated with terrain diversity in two ecoregions, and negatively associated with terrain diversity in two ecoregions. In three ecoregions, cells containing a loss had a significantly lower percent cover of herbaceous habitat than those containing a presence. In another three ecoregions, cells containing a loss had a higher percent cover of hardwood forest (Table 3.4). Variable screening and stepwise regression resulted in between one and six variables remaining in final models for each ecoregion (again, the Modoc ecoregion was excluded as no variables differed significantly). Classification accuracy for losses in badger sightings varied across the ecoregions, but was generally poor, ranging from 0% to 64.3%. Presences were predicted with higher accuracy: between 73.7% and 100.0% (Table 3.5).

Table 3.4: Univariate relationships between losses in badger occurrences and habitat variables. Sign indicates the direction of the relationship; significance of relationship is indicated as follows: $P < 0.1$ (+/-), $P < 0.05$ (++/--), $P < 0.001$ (+++/---).

Variable	Cascade	Central West	Modoc	Mojave	Northwest
Average elevation	–			++	++
Terrain diversity		– –		++	+
Road density		++			
% Agriculture		– –			
% Hardwood woodland	+				– –
% Hardwood forest	+				
% Conifer woodland					
% Conifer forest	–				+
% Urban	+	++		– –	
% Wetland		++			
% Shrub				+	
% Herbaceous		– –			–
% Barren					

Table 3.4 (cont.): Univariate relationships between losses in badger occurrences and habitat variables. Sign indicates the direction of the relationship; significance of relationship is indicated as follows: $P < 0.1$ (+/-), $P < 0.05$ (++/--), $P < 0.001$ (+++/---).

Variable	Sierra	Sonora	Southwest	Great Valley
Average elevation				
Terrain diversity		--		
Road density				
% Agriculture				
% Hardwood woodland		--		
% Hardwood forest	+++			+
% Conifer woodland		--		--
% Conifer forest				
% Urban				
% Wetland				
% Shrub			-	
% Herbaceous		--		
% Barren		--	-	

Table 3.5: Variables contained in multiple logistic regression models for losses in badger occurrences; showing coefficients, standard errors, and significance values.

Ecoregion	Variable	Coefficient	1 SE	χ^2	*P*	Occurrences correctly classified (% of losses/ % of presences)
Cascade	Intercept	-3.537	2.249	2.47	0.116	42.9 / 95.0
	Average elevation	-0.001	0.001	4.19	0.041	
Central West	Intercept	3.109	0.875	12.62	<0.001	35.7 / 96.8
	% Urban	0.064	0.020	10.71	0.001	
	% Herbaceous	-3.109	0.875	12.62	<0.001	
Mojave	Intercept	3.687	1.313	7.88	0.005	26.6. / 95.6
	% Urban	-3.686	1.313	7.88	0.005	
Northwest	Intercept	1.130	0.664	2.89	0.089	56.5 / 76.0
	Average elevation	0.001	0.001	3.07	0.080	
Sierra	Intercept	1.771	0.439	16.28	<.0001	38.5 / 97.2
	% Hardwood forest	0.171	0.069	6.11	0.014	
Sonora	Intercept	-1.129	0.756	2.23	0.135	64.3 / 73.7
	Terrain diversity	-0.246	0.123	4.00	0.046	
Southwest	Intercept	-0.177	0.700	0.06	0.801	0.0 / 100.0
	% Shrub	-0.029	0.015	3.70	0.054	

DISCUSSION

Distribution of modern badger occurrences

Badgers are generally considered to be associated with grassland and shrub habitats on broad scales (Hoff 1998, Apps *et al.* 2002, Collins 2003, Hoodicoff 2003, Chapter 1). Here, this relationship held true in the Northwest, Mojave, Southwest, Sonora and Great Valley ecoregions, where the percentage of herbaceous vegetation (a classification that groups several different types of grasslands) was associated with badger occurrences; and in the Sonora, Sierra, and Great Valley ecoregions, where an association with shrub and/or desert shrub habitat was detected. To some extent, occurrences in these habitat types likely reflect the distribution of badgers' preferred prey populations in the landscape, such as California ground squirrels (*Spermophilus beecheyi*), Townsend's ground squirrel (*Spermophilus townsendii*), Botta's pocket gophers (*Thomomys bottae*), meadow voles (*Microtis californicus*), and kangaroo rats (*Dipodomys spp.*) (Grinnell *et al.* 1937). Many of these species are associated with grassland and scrub habitat types. Badgers may also use shrub habitat for cover for den placement, but this pattern of association may be stronger at the home range scale (Sargeant & Warner 1972, Chapter 1).

Badger occurrences also were associated with hardwood woodlands, conifer woodlands, and conifer forest. These results seem inconsistent with previous studies, where a negative association with forest cover was found (Apps *et al.* 2002). Hardwood and conifer woodlands are often found in association with grasslands and shrub habitat (Mayer & Laudenslayer 1988; although I did not detect any correlation between these habitat types at the scale of analysis used here). As badgers do disperse or move through a mosaic of less-preferred habitat types, particularly during the breeding season (Chapter 2), badger occurrences at the boundaries of their most preferred habitat types is likely. Similarly, badgers are known to occur in alpine meadows within conifer forests (Grinnell *et al.* 1937); a habitat type that may not be well-captured at the 100 meter resolution of the land cover layer used in this analysis. Badger occurrences were also related to a higher average elevation (Cascade and Great Valley ecoregions) and a higher index of terrain diversity (Modoc, Sonora, and Great Valley ecoregions). Again, in previous studies, badger presence has been found to be negatively associated with elevation (Apps. *et al.* 2002). However, in California, an association with elevation or terrain diversity may indicate the population distribution of badgers in foothill areas (i.e. along the margins of the Great Valley); or the more productive mountainous parts of the desert ecoregions (Modoc and Sonora). Human settlement and activity tends to be concentrated at lower elevations as well, perhaps limiting badger persistence. Alternatively, high elevations or rugged terrain may serve as surrogate variables for intermediate to steep slopes. Within their home range, badgers do avoid flat terrain for denning (Chapter 1), perhaps due to poor drainage and/or increased energetic expenditure required to dig into flat ground, and thus may prefer hilly or mountainous habitat. However, it is unlikely that such an effect would be detected at this geographic scale.

Variables that quantified the human-impacted landscape, road density and agriculture, were positively related to badger occurrence in some ecoregions. Badgers have been shown to select human-modified, linear or disturbed habitats in British Columbia; perhaps reflecting an attraction to prey species that can occur at high densities in these landscapes (Apps *et al.* 2002, Hoodicoff 2003). Moreover, as British Columbia lies at the northern edge of their range extent, it is possible that resources for badgers are more limited than in the core of their range (as in California); thus they exhibit a stronger preference for productive, human-modified areas. Such a pattern in California may indicate similar resource limitation in these ecoregions for badgers. Badgers have been recorded as "pests" in agricultural areas of California previously; perhaps drawn by high prey densities (Minta & Marsh 1988). Moreover, in the Central West ecoregion, agricultural fields are often near or adjacent to foothill habitat that support badger populations; thus badgers may incorporate these fields into their larger home range. It is interesting to note, however, that an association with road density occurred primarily in the lesser populated, more remote ecoregions of California: Northwest, Mojave, and Modoc. Thus, this pattern may also reflect a distribution of observers more strongly associated with roads than in more populated ecoregions, where human activity away from roaded areas may be more common. It is also likely that road-killed animals accounted for some of the sightings or specimens used in this analysis, which would potentially account for this association. However, reports did not consistently distinguish whether sightings or specimens were of road-killed or live animals, preventing the analysis of this effect.

Distribution of losses in badger occurrences

Because the data layers available for analysis were based on recent satellite images, and because historic vegetation maps are not yet fully digitized, it is difficult to determine the specific association between losses in badger occurrences and habitat change (for example, declines in badger occurrences due to changes in forest structure, or conversion of forest or shrubland to grassland). Losses associated with human-modified landscapes; however, can more likely be attributed to habitat change. Most agricultural development occurred by the 1960s; and suburban and urban development is even more recent (Bunn *et al.* 2007). Thus historic badger sightings in these types of habitat (according to current maps) were likely to have actually occurred in another habitat type.

Declines in badger occurrences in some ecoregions suggested that losses occurred within currently suitable habitat. For example, in the Sierra ecoregion, modern badger occurrences were positively associated with percent hardwood forest vegetation, and losses were also associated with this habitat type. These patterns may reflect a pattern of observer traffic lessening in these areas over time, especially in the remote Modoc ecoregion. However, given the limited extent of historic records compared to modern ones, this explanation seems more unlikely for the Sierra ecoregion. Here, it is difficult to speculate on the specific cause of apparent badger declines. Much of the hardwood forest in the Sierra ecoregion is in private ownership, which could account for the relatively few sightings occurring there. Privately-owned hardwood forests can also be subject to stressors such as grazing, logging, clearing for agriculture or development (Davis *et al.* 1998). Deforestation alone is not necessarily detrimental to badger persistence; in eastern states, badgers may be able to expand their range when logging results in more suitable habitat becoming available (Nugent & Choate 1970, Gremillion-Smith 1985). However, direct control of badgers in conjunction with these activities may still reduce populations (Minta & Marsh 1988). Moreover, secondary effects of control of prey populations associated with agricultural activities (direct reduction of prey base, or secondary poisoning) may also adversely affect badgers (Quinn *et al. in prep*).

Human activity was associated with losses in badger occurrences in only two ecoregions. In the Mojave ecoregion, losses occurred in areas with low percent cover of urban area. As with the positive association between modern occurrence and road density, this result may reflect the distribution of observers, particularly due to the sparse human population of the region. Alternatively, badgers in this perhaps resource-limited, desert habitat may also enjoy increased resource abundance (i.e. prey populations, water availability) near human-settled areas. In the Central West ecoregion; however, losses in badger occurrences were *more likely* where percent urban cover was higher. An observer effect in this situation seems unlikely due to the amount of human population growth in this region (Bunn *et al.* 2007); such an effect would likely produce the opposite pattern. This result may highlight the adverse effect of roads on badgers; although road density was not a factor considered in the final model due to correlation with urban percent cover. The impact of roads on badger survival has been documented elsewhere. In a British Columbia study, 7 of 10 radio-marked individuals were killed crossing transportation corridors, 6 by vehicles and 1 by a train during the 4-year study. Thirteen untagged badgers were also killed in vehicle collisions within the same (~4000 km^2) study site during the same time period (Hoodicoff 2003). Likewise, Messick *et al.* (1981) report 59% of 157 badger mortalities in an Idaho population resulting from vehicle collisions. Anecdotal data also exist for California, and for the Central West ecoregion in particular. In Monterey County, California; 8 road-killed badgers were reported or observed adjacent to a 60 km^2 Fort Ord study area during a 9-month period (Chapter 1). Further, 7 road-killed badgers have been reported in Santa Clara County along a 10-km stretch of highway between 2006 and 2007, near an area where a natal den was observed in 2006 (Congdon, Santa Clara Animal Control *pers. comm.*). Badgers seem particularly unable to cross highway medians due to their low-slung stature (Hoodicoff 2003; Congdon, Santa Clara Animal Control *pers. comm.*).

Model performance

Logistic regression models varied in their performance by ecoregion. In only a few cases were models good predictors of modern badger occurrences, and in many were poor predictors of losses in badger occurrences. There are several potential sources of the large amount of unexplained variation in these models. Opportunistically-collected occurrence data will inevitably be subject to high amounts of observer error and sampling bias, even after attempts at screening more dubious records. Given that these data were the most extensive sources of badger occurrence available, and that it would be impossible to verify most occurrence records (especially historic records), this source of variation is unavoidable due to the nature of this analysis. Moreover, spatial accuracy errors that can result from overlaying multiple GIS layers may also contribute to uncertainty (Heuvelink 1998).

Variation in the models may be due to the fact that factors affecting badger occurrence are not well-described by the habitat characteristics included here. For example, some land cover classifications used in this analysis may not reflect the actual vegetative structure to which badger occurrence responds; such as stand density, greenness indices, or measures of primary productivity. Moreover, the mapping resolution of the data used here may not have been sufficient to capture true habitat associations. Historical or stochastic events may also affect badger occurrence or loss of occurrences, such as catastrophic fires or large-scale predator control operations—these factors may not necessarily be related to habitat characteristics or quality. Low habitat saturation independent of these events may also play a role. Additionally, spatial characteristics of the landscape, such as measures of habitat fragmentation, may also have an effect. Particularly for wide-ranging species, spatial factors such as patch size, isolation, and characteristics of the matrix that must be used or crossed can be important determinants of occurrence (Crooks 2002, Virgós *et al.* 2002, Fleishman *et al.* 2002, Krawchuk & Taylor 2003, Sisk *et al.* 1997, With & King 1999, Ricketts 2001, Brotons *et al.* 2003, Goodwin 2003, Selonen & Hanski 2003).

Finally, male and occasionally female badgers are particularly wide-ranging during the breeding season (Minta 1993, Goodrich & Buskirk 1999, Collins 2003, Hoodicoff 2003, Chapter 2), and thus may be more frequently sighted, trapped, or road-killed during these times. Such a trend has been observed in Eurasian badgers (*Meles meles*) as well (Davies *et al.* 1987). At the same time, badgers' movement during the breeding season may not always be driven by habitat characteristics; but by a desire to find mates (Chapter 2). Thus, occurrence records may tend to include encounters with badgers in travel habitat (which may be highly variable) rather than in habitat required for foraging, daytime denning, and/or reproduction (Chapter 2).

Management implications

This analysis of current and historic badger population distribution using occurrence records should be considered a preliminary assessment. Based on poor predictive value of the models, and the substantial differences in results between ecoregions, conservation planning at this scale may not be appropriate. The limitations of this analysis could potentially be overcome by a more rigorous sampling design (see Palma *et al.* 1999, Rodriguez & Delibes 2002). While the intention of this study was to make use of existing data, future analyses could be aimed at developing a systematic sampling program throughout the state; either through direct, verifiable interviews; or by establishing passive monitoring stations (Quinn & Diamond *in prep*). Such an approach may also address the problem of establishing true absence, which is always subject to uncertainty (Karl *et al.* 2002). With systematic sampling, at least some of this uncertainty can be quantified and explained. Moreover, animals respond to habitat characteristics on multiple scales. Gathering more verifiably accurate occurrence locations would further allow a multi-scale assessment of habitat associations (spatial habitat data permitting) rather than the fairly coarse scale used here.

The results presented here do highlight issues that warrant further research and attention. While existing range maps for badgers indicate a continuous range throughout the state, it is difficult to determine if the range represented by these occurrence records is truly continuous. The existence and extent of movement between occurrence clusters is unknown. The maximum distance from any one occurrence to the nearest adjacent occurrence is approximately 60 km, and while this distance is within the known dispersal capabilities of a badgers in Idaho and British Columbia (Messick & Hornocker 1981, Hoodicoff 2002, Newhouse & Kinley 1999), this scale of dispersal has not yet been recorded in badgers in California. Moreover, the distances between clusters of occurrences on either side of the northern Great Valley, as well as either side of the Mojave Desert, exceed 100 km (Fig. 3.4). Again, although a few badgers have been recorded traveling this far elsewhere, this scale of movement has not yet been documented in California. Thus it is not known to what extent geographical features or human-modified landscapes—especially across the Great Valley—function as barriers between these clusters of occurrences. Moreover, three ecoregions had almost as many losses in badger occurrences as records of presence: the Northwest, Sonora, and Great Valley. Focused survey efforts may prioritize establishing badger presence in the gaps between occurrence clusters, and in ecoregions where declines in occurrences seem prevalent.

That the factors affecting badger occurrence are so varied throughout California indicates that threats to badger populations, as well as the effects of those threats on population persistence, may well be just as varied. Identifying and understanding these threats, and the scale at which they affect badger populations, will allow managers to better determine the appropriate scale for initiating conservation action. Although listed as a Species of Special Concern, badgers have not yet widely been included in the design of regional conservation plans in California, primarily due to the lack of data regarding population range extent and ecology (Quinn & Diamond *in prep*). Data presented here can constitute a coarse baseline against which to compare future ecological conditions, and to better assess the effect of human impacts and habitat change on badger populations.

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SUMMARY

The data presented in this dissertation provide a basic foundation for developing the American badger as a focal species in conservation planning in California. Chapters 1 and 2 established preliminary spatial requirements for core and corridor habitat, and suggested how these factors may vary according to season or gender. Chapter 3 provided a better understanding of badger population distribution and persistence statewide, allowing assessments of the role of the badger as a focal species specific to geographic regions across California. In addition to those three chapters, I also used a review of the literature, as well as assessments of both health (Appendix A) and monitoring methods (Appendix B, C) to further evaluate the threats, conservation status, and management needs of badgers in California, detailed below.

Habitat Fragmentation and Loss

Because of badgers' high capacity for long-distance movement, historic gene flow may have been sufficient to maintain population growth and genetic variation across badger populations in California. However, extensive habitat loss throughout their range, combined with badgers' sensitivity the effects of habitat fragmentation, may have isolated populations statewide. If this is the case, these isolated populations may be more susceptible to extirpation due to disease outbreaks, loss of genetic variation, or negative demographic trends. Recent genetic research in Canada indicated reduced gene flow between populations separated by mountain ranges within a subspecies (*T. taxus jeffersonii*) (Kyle *et al.* 2005). Moreover, as badgers' breeding rates can be relatively low (with females reproducing only ever other year) and juvenile mortality rates may be high (as much as 75% in some populations), both of these factors would lead to declines in populations that are geographically isolated from immigration. As indicated in Chapter 3, the current distribution of badger sightings suggests that their range may not be continuous. Agricultural and residential development in valley grasslands may constitute barriers between populations in the mountain and foothills (i.e. the Santa Cruz and Coastal Ranges, the Diablo Range, and the Sierra Nevada), and extensive urban development may likewise isolate coastal populations. Genetic structuring due to both natural and anthropogenic barriers in California has been observed for mountain lions (*Felis concolor*) (Ernest *et al.* 2003). As badgers are far less physiologically mobile than mountain lions but still wide-ranging, we expect them to be even more impacted by the large-scale fragmentation of their habitat.

Current land protection in badger habitat may not be sufficient to support connectivity between populations in the long term. Although unprotected habitat may not be currently fragmented, the state of this habitat can not necessarily be assured in the long term. The California GAP analysis report (Davis *et al.* 1998) quantified land ownership based on habitat type throughout the state, as well as a ranked degree of maintenance of biodiversity for each USGS quadrangle. A status of "1" denotes the highest, most permanent level of maintenance, and "4" represents the lowest level of biodiversity management, or unknown status. Redwood forest, oak woodlands, annual grassland, and coastal scrub tend to be primarily in private ownership, and are thus susceptible to potential conversion to agricultural and urban/suburban development. Of the 45 native habitats not converted to human-dominated uses, 12 have less than 10% area in status 1 or 2 managed areas. These least well-represented habitats include most of the hardwood woodland types, coastal scrub, grasslands, and a few habitat types occurring in the Great Basin such as juniper, bitterbrush, low sage, and Eastside pine. Accordingly, most of these habitat types occur primarily on private lands. Most of these habitats with a low protection status are the highest quality badger habitat; including annual grasslands, of which 86.5% are under private ownership (Davis *et al.* 1998).

Badgers potentially require large amounts of intact habitat for populations to persist (Crooks 2002). As determined in Chapter 1, badgers have relatively large home ranges of up to at least 26 km^2. To maintain a group of badgers, an area of at minimum over 100 km^2 may be required. Ultimately, this protected area size will depend on a further understanding of badger population demographics and population viability. Because existing protected areas will likely not be sufficient for conservation of badger populations statewide, conservation efforts should be focused toward the future acquisition of suitable habitat, or toward developing conservation partnerships with private landowners to encourage land-use practices that maintain extant badger populations.

In addition to maintaining large areas of suitable core grassland habitat, providing connectivity between core areas can help maintain viable badger populations via maintenance of demographic and genetic exchange between populations (Messick & Hornocker 1981). Data presented in Chapter 1 and Chapter 2 of this dissertation can help in defining habitat types that badgers utilize to travel outside of their home ranges, which is critical in delineating corridors for badgers.

Road mortality

Although road mortality seems to be a significant source of badger mortalities, I did not specifically document the effect of roads on badger movement behavior here. However, badger movement behavior, particularly an increased potential to use marginal habitat during the breeding season for males (Chapter 2), still creates cause for concern. On the statewide scale, results from Chapter 3 indicated that losses in badger occurrences are associated with high urban densities in the Central West ecoregion. Anecdotal evidence (Chapter 1, Chapter 2) provides further support that road mortality may be a significant factor in badger population declines.

To minimize the likelihood of mortality due to vehicle collisions on roads, safe passage between existing badger habitat across high-use roads may be required. One type of corridor design that may be beneficial for badgers is to provide fencing to guide badgers to culverts running under high use roads where there has been a high rate of badger mortality. By coordinating badger monitoring efforts with organizations seeking to assess connectivity for badgers, more research on badger movement through landscapes could be achieved. For example, in Santa Clara County, land managers developing the Santa Clara HCP, and the Silicon Valley Land Conservancy (whose lands have resident badgers) have been pro-actively engaged in planning for badger movement across travel corridors. As part of these plans for connectivity, the collection of reports of road-killed badgers by various transportation and animal control agency will help to identify problem crossing areas, and culvert crossings or underpasses will be established where they would be most effective.

Disease

Because much of the badger's core habitat is increasingly being encroached by development, the proximity of remaining badger populations to humans and domestic animals raises concern about the potential transmission of disease between the species. However, almost nothing is known of disease occurrence in badgers in California. As part of a study investigating the movement of badgers in a fragmented landscape in central California, blood samples were collected from radio-marked badgers to conduct a serological survey (Appendix A).

The common or excessive exposure of animals to highly pathogenic diseases often warrants further investigation into the identification and pathology of specific diseases, perhaps through the dedicated search for infected animals and carcasses. As this level of exposure has not yet been observed, disease management at this point can be responsive, pending the observation of inexplicable badger mortalities that are not due to vehicle collisions or predation (which could indicate a possible disease outbreak). Opportunistic disease surveillance of road-killed carcasses or of animals trapped for harvest or depredation can also serve to track the occurrence of diseases in badgers. If epidemic, fatal diseases are detected, options for containing the disease through vaccination or quarantine can be explored.

Anticoagulant poisoning

Badgers may also suffer secondary exposure to anticoagulant rodenticides, which are often used around residential areas and in agricultural fields, through the consumption of poisoned prey. The slow action of these anticoagulants often assures that the target animal that consumes it has time to return to its burrow before succumbing to the toxin, thus minimizing the above-ground exposure of non-target predators and scavengers of the carcass. However, secondary poisoning still does occur. For example, rodenticides have been detected in 31 of 39 bobcats (*Felis rufus*) tested in southern California, and caused the death of 2 mountain lions (Riley *et al. in press*). Moreover, this exposure to anticoagulants may have increased the susceptibility of these animals to notoedric mange, tripling mange-related mortality rates in the population (Riley *et al. in press*). Animals that consume an entire poisoned rodent carcass (as would a badger) are most at risk of secondary poisoning. Badgers also primarily dig for their prey, and therefore may be at an even higher risk (compared to other carnivores) of exposure to poisoned rodents underground.

Ingestion of anticoagulants by badgers has not been documented previously. However, badgers' primary prey items, California ground squirrels (*Spermophilus beecheyi*) and Botta's pocket gopher (*Thomomys bottae*), are often controlled using diaphacinone and chlorophacinone in agriculture. In developed areas, rodent pests are often poisoned with commercially available brodificoum. As part of the above-mentioned serological survey, serum samples were also screened for the presence of anticoagulant rodenticides. Liver samples obtained during routine necropsies of two animals that died during the course of the Monterey County study, and from one road-killed animal that was collected in Los Angeles County were also analyzed. All serum samples tested negative for the presence of anticoagulants, as did the 2 liver samples from the animals in Monterey County. The liver sample of the animal from Los Angeles County contained trace amounts of brodificoum (Appendix A).

The California Department of Pesticide Regulation is reevaluating brodifacoum at the request of CDFG, addressing concerns that the currently registered uses expose California's wildlife to its adverse effects (Department of Pesticide Regulation 2000). Because animals typically retreat to dens, burrows, or unobtrusive roots in the final stages of anticoagulant poisoning, exposure of non-target wildlife to this compound may be more extensive than is indicated by available data. Due to the potential risks, a conservative management approach should dictate that the use of anticoagulant poisons should be minimized when badgers are known to be present, particularly during the breeding season. Pre-application surveys may be an effective way to establish badger presence in areas to be treated. Because badgers tend to move frequently, once badgers leave the area, bait application could then take place.

Trapping

Compared to other furbearer species, the badger's lower reproductive potential may make it particularly susceptible to population declines under heavy levels of harvest (Drescher 1974, Salt 1976, Long and Killingley 1983, Minta & Marsh 1988). In North America, there was an exponential increase in badger pelts marketed between 1972 and 1978—from 2,000 pelts to 42,000—due to a substantial increase in the demand for long-hair fur and subsequent rise in pelt prices (Long & Killingley 1983). In 1981, that there was an increase in badger trapping regulations due to concern over badger population declines from this elevated fur harvest during the 1970s (Minta & Marsh 1988).

According to USDA-APHIS data, badgers were also heavily trapped from 1978-87, due to reported crop and irrigation damage resulting from badger digging. During this ten-year period, 1,456 badgers were destroyed. Another 23 badgers were trapped and then released. An additional 843 badgers were trapped accidentally as non-target species (as a result of management of other pest species); of these, 589 were released. Badgers may also be trapped in high numbers for depredation by persons and entities besides USDA-APHIS. For example, in a 2004 hunter's survey, 34 hunters reported taking a total of 168 badgers from Siskiyou County for depredation in 2003-2004 (Lauridson 2005). As no formal reporting is required for this activity, the extent of these numbers beyond that report is indefinite.

The effects of current trapping regulations on badger populations are unknown. If the rate of badger harvest is higher than the badger's reproductive rate, and occurs on a large enough scale, it could contribute to population declines. However, given the lack of reporting requirements for depredation take, as well as the lack of knowledge regarding badger population sizes and growth rate, determining sustainable levels of harvest or control is not currently possible. Determining sustainable levels of badger harvest through trapping (those that would not contribute to population declines), and tracking these levels through permitting and reporting may help to preserve viable badger populations in the long term.

Trapping of badgers is often due to perceived conflict with human endeavors (Minta & March 1988). Thus, preventative actions ameliorating this conflict may reduce the need for active control of badger populations. Because of the badger's digging activities, some horsemen and cattle ranchers fear that horses and cows will step in burrows, resulting in a broken leg or thrown rider (Hawbaker 1969, Long & Killingley 1983). However, there have been few reported cases of horse injury, and it has been found that cattle are much less prone to such accidents than anecdote would suggest (Minta & Marsh 1988). Thus, in California and much of western America, badger presence around livestock may not typically be considered a significant problem, and perhaps rarely requires the corrective action of removing badgers. However, exceptions can be made where badger burrowing occurs in horse-riding arenas, jumping courses, or in or alongside a frequently used equestrian trails. Riders unfamiliar with the terrain should be warned of the hazards of badger dens and diggings so they can avoid those areas or at least avoid galloping through those particular pastures (Minta & Marsh 1988).

It has been noted that badgers may cause economic losses to individual farmers or landowners through digging in agricultural areas, such as alfalfa fields (Johnson 1983). However, in California, these occurrences are few relative to the vast acreage in agricultural production. Reducing the availability of badger prey, such as pocket gophers and ground squirrels, has been suggested as a method to reduce badger activity (Minta & Marsh 1998). However, removing prey species through poisoning is not recommended since secondary poisoning from ingesting rodenticide-poisoned animals may be a threat to badgers. Moreover, in California, badger damage due to digging is so infrequent, that the large-scale removal of badger prey species to prevent badger digging is not particularly cost effective (Minta & Marsh 1988). Relocation of badgers may be a better management option where damage is severe. Further assessment of relocation methods a better management option where damage is severe. Further assessment of relocation methods would be needed; however, due to badgers' opportunistic foraging habits, loose territorial structure, and propensity to travel long distances on their own, this option may prove a viable one. Relocation should always be avoided; however, during the spring and early summer, when mothers and dependent kits may be separated. Moreover, relocation efforts should only be pursued pending further data regarding the genetic structure of badger sub-populations.

Current conservation

The Species of Special Concern listing status for badgers has directed research funding through RAP to a conservation assessment of the species' status. The listing has also prompted the consideration of badgers in some conservation planning efforts. For example, badgers are considered a focal species in a few Habitat Conservation Plans (HCP), Natural Community Conservation Plans (NCCP), and Multiple Species/Habitat Conservation Plans (MSCP, MSHCP) throughout the state. Specifically, the Western Riverside County MSHCP and the San Diego MSCP both include badgers as a covered species. In HCP/NCCPs under development for Yolo County and Yuba/Sutter Counties, badgers have been recommended for consideration in reports issued by their respective Scientific Advisory Committees. According to a report issued by the Scientific Advisory Committee for the Santa Clara County HCP/NCCP, badgers were recommended for consideration of coverage. However, they were ultimately not covered due to the unlikelihood of future uplisting, as well as cited data on badger range expansions in Midwestern states. Several other county/regional conservation plans are either completed or are under review in areas where badgers are known to occur that neither consider nor cover badgers as a planning species (Appendix D). The non-governmental organization South Coast Wildlands Project considers badgers in all of its habitat linkage designs (Penrod *et al.* 2001, 2003, 2004, 2005, 2006). Most recently, badgers were considered a primary focal species in assessing habitat linkages in Santa Clara County in the Elkhorn Slough Coastal Training Program's Sierra Azul Connectivity Workshops (Coastal Training Program 2007).

The inclusion of badgers as a planning species in conservation plans is likely beneficial. Most planning documents are supplied online; and many are part of a web portal providing information about reserve habitats and species. As badgers are a very charismatic species, this public exposure may foster the public's interest and appreciation of badgers, especially in areas where badger occurrence is not common knowledge. For example, research on badgers in Chapters 1 and 2 of this dissertation garnered five newspaper articles and overwhelming public interest. The involvement of the public led to invitations for several speaking engagements, the receipt of many reports of badger sightings, and the fostering of a general conservation interest. Moreover, the inclusion of badgers as a covered species in conservation plans should ensure that populations will be monitored in the future, and that their habitat requirements are met. Specifically, badgers may serve as one of the more sensitive measures of minimum reserve size and connectivity for grassland and scrub habitat types. As a cautionary note, plans that do cover badger have until recently had only biological data on badger habitat and spatial requirements from outside the state of California available to inform conservation actions. Newly emerging data, such as those outlined in this report, may necessitate the also call for consideration of badgers during future reviews of plans that do not cover them currently.

Additional data required for management

The largest obstacle to implementing more effective badger management is the current lack of knowledge regarding the ecology of the statewide population. Recent gains in understanding of badger habitat preferences and movement behavior, patterns in statewide distribution, and projections of habitat fragmentation; however, provide a fairly solid foundation from which to establish research direction aimed at obtaining this knowledge.

Short term monitoring

Perhaps the most needed management tools are means of monitoring badger presence and population sizes. Because of the cost and labor intensity of badger capture and radio-telemetry (as well as potential risks, see Appendix B), passive monitoring methods may be used where resources are limited. I compared four methods of surveying for badgers: spotlighting, burrow searching, camera trapping, and scent station monitoring (Appendix C). While none of these can provide detailed movement data that is possible with radio-telemetry, if the goals of an assessment include documenting corridor/habitat usage, monitoring reproduction, establishing presence/absence or population density, or measuring the impact of human activities or habitat modification on any of these factors, passive monitoring methods can be implemented and tailored to provide useful data.

Transect searching for badger burrows was the most useful method for conducting badger surveys. Spotlighting and camera trapping did not detect badgers at all, and scent stations had a very low detection rate. Transect searching; however, may overestimate badger population density, as several transects can likely be visited by the same badger and thus can not be considered independent. Likewise, badger numbers may be underestimated by transect searches if the survey design involves several transects crossing more than one home range (i.e. home ranges of the badgers in this study were significantly overlapped, see Chapter 1). Thus, a detection at one transect may be actually due to activity from more than one badger. Transect searching can indeed verify badger presence, however, and was superior to all other methods in this regard. It is actually potentially less cost and labor-intensive than other methods, as no special equipment is used, and searches can be completed in a relatively short amount of time (each transect takes less than an hour). Adequate training is required to identify badger burrows; however, this training may be far less intensive than that required for installing camera stations or identifying animal tracks at scent stations. For establishing presence/absence of badgers in a given area, sampling intensity can likely be scaled according to probable badger density in order to cover more ground. For example, at Fort Ord, 1-km transects spaced 2 km apart would have resulted in six (by new activity) or eight (by old activity) detections when eight badgers were known to be present. As badger populations at Fort Ord may be denser and home ranges smaller than those in other areas, transects could probably be spaced even further apart in areas where sign is rarer.

Long term monitoring

Systematic monitoring of badgers using an established method could be conducted regularly. The regular collection of sighting reports from an established list of contacts may provide more coarse statewide data needed to determine range extent, and to assess changes in that extent over time. Optimally, the state may be divided into grid cells, and a presence/absence can be recorded for each cell through the collection of sightings data at regular intervals (i.e. every 5 years). In all publicly-owned lands or protected areas, badger surveys using the transect search method could be conducted regularly as well. Finally, requiring the reporting the number and general location of badgers killed for depredation, as well as for recreation and profit, will provide further population distribution data at the statewide scale.

Demographic data

To properly assess the trajectory of populations locally, as well as to extrapolate those data regionally, knowledge of badger demographic data is needed. In particular, data regarding age-specific mortality rates and reproductive rates can be used to conduct population viability analyses, and to establish minimum viable population sizes. Moreover, demographic data can be linked to habitat and spatial data as well to model the effect of land-use changes and management actions on population growth in the long term. Demographic data can be most reliably collected through long-term radio telemetry of badgers, perhaps focusing on a few populations across the state.

Genetic structure of populations

An understanding of the genetic structure of badger populations in California is needed to identify barriers to gene flow between populations, to inform conservation planning efforts that promote connectivity in grasslands, and to direct local management of badger populations. Appropriate management for populations may vary geographically; however, as threats facing a population in one area may differ from those facing a population in another. Moreover, a highly insular population may be more vulnerable to extirpation and require additional protections. An ecological framework for applying conservation actions at the local scale may be required to maintain the badger population statewide.

Genetic analysis would require the collection of tissue samples from badgers throughout the state. Badgers are extremely difficult to live-capture on such a large scale; likewise at this scale, the use of hair snares is likely to be prohibitively labor-intensive. Thus, efforts could focus on opportunistically gathering samples from badger carcasses obtained from existing trapping operations, or collected as road kill throughout the state. Collection efforts could be conducted through maintaining contact with personnel that regularly encounter badgers in the field. Efforts could be aimed at regions of the state where geographic separation of badger populations is suspected, such as in each of the Jepson ecoregions.

Conclusion

Based on the data collected for this dissertation, and on review of the available scientific literature, I conclude that the American badger is rightfully listed as a Species of Special Concern. At present, there are not enough data to warrant a status upgrade to Threatened or Endangered. However, given the known aspects of their behavior and ecology, as well as the threats described in this report; we can reasonably conclude that the badger's conservation status still merits concern. Particularly, the continued loss and fragmentation of core habitat, especially in the proximity of roads is likely to isolate populations locally, leading to potential declines and even extirpations. Such local extirpations may precede larger range contractions throughout the state. However, given the lack of monitoring for badgers statewide, the lack of recording numbers trapped for depredation, and the absence of demographic and genetic data; population isolation and subsequent declines may in fact be currently intractable.

The badger would also serve as an excellent focal species for conservation planning across the state. The active inclusion of badgers in appropriate conservation plans—as well as the application of current data on badger populations and ecology from California to the development of conservation measures—will likely constitute an important first step in establishing more effective management. The further large-scale monitoring of badgers through quantifiable surveys, as recommended by Larsen (1987), required reporting of trapping take for depredation, and analysis of population genetics will better elucidate population distribution, size and growth trends. Finally, further research aimed at understanding population demographics under harvest, disease risk, and ecotoxicology will better clarify the mechanisms through which fragmentation affects badger persistence. Conservation of badger habitat will only preserve populations if these other threats can be addressed and minimized.

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APPENDIX A

A SEROLOGICAL SURVEY AND ANTICOAGULANT SCREEN OF AMERICAN BADGERS (*TAXIDEA TAXUS*) AT THE URBAN-WILDLAND INTERFACE

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Abstract

Habitat fragmentation by urban development has potentially increased the risk of disease transmission between American badgers and domestic animals or humans. Urban encroachment may also lead to exposure of badgers to anticoagulant rodenticides commonly used in urban areas. We screened blood and tissue samples from 10 badgers for diseases found in domestic animal populations and those posing a risk to livestock and public health. We tested liver samples of 3 animals and blood samples of 8 animals for exposure to rodenticides. 7 animals tested seropositive for antibodies for Canine Distemper Virus, Toxoplasma, and anaplasma. 1 liver sample contained trace amounts of the rodenticide brodificuom.

INTRODUCTION

The American badger (*Taxidea taxus*), a semi-fossorial mustelid of the open grasslands, is currently listed as a Species of Special Concern in California. Populations have likely declined significantly since the late 1800's due to indiscriminate trapping, conversion of habitat to agriculture, and depletion of prey populations (Grinnell *et al.* 1937). With their large home range sizes and dispersal distances, as well as high mortality rates from vehicle collisions (Hoodicoff 2003, Quinn & Diamond *in prep*), badgers are significantly affected by the effects of habitat fragmentation. Recent research suggests that, more than other California carnivores, badgers are restricted to contiguous habitat in urbanizing landscapes (Crooks 2002). Thus, assessing the conservation status of *Taxidea* is a priority in California, as they are considered as a focal species in developing several regional conservation plans in grassland habitats, among the least-protected habitat types in the state (Davis *et al.* 1998, Olsen & Cox 1999).

Because badger habitat is increasingly being encroached by development, the proximity of remaining badger populations to humans and domestic animals raises concern about the potential transmission of disease between the species. However, almost nothing is known of disease occurrence in badgers in California. As part of a study investigating the movement of badgers in a fragmented landscape in central California, blood samples were collected from radio-marked badgers to conduct this serological survey. We focused our assessment on the detection of diseases that result from exposure to domestic animals found in the urban areas adjacent to the core study site; including tests for the presence of antibodies to Canine Distemper Virus (CDV), Canine parvovirus, and *Toxoplasma gondii*. Additionally, we tested for the occurrence of antibodies for pathogens with a known risk to livestock and public health, including plague (*Yersinia pestis*), Lyme disease (*Borrelia burgdorferi*), leptospriosis (*Leptospira* sp.), Johne's disease (*Mycobacterium paratuberculosis*), and anaplasma (*Anaplasma phagocytophilum*). CDV (Williams *et al.* 1988, Goodrich *et al.* 1998), plague (Smith 1994, Salkeld & Stapp 2006), and Toxoplasma (Marchiondo *et al.* 1976) have been recorded at low prevalence in badgers. Johne's disease has not been documented in badgers, although the occurrence of another strain of *Mycobacterium*, bovine tuberculosis (*Mycobacterium bovis*), has been well-studied in European badgers (*Meles meles*) (Cheeseman *et al.* 1989). Bovine tuberculosis has not been detected in American badgers (Schmitt *et al.* 2002).

Badgers may also suffer secondary exposure to anticoagulant rodenticides which are used around residential areas and in agricultural fields, through the consumption of poisoned prey. Thus, we also screened for the presence of anticoagulants. Ingestion of anticoagulants by badgers has not been documented. However, badgers' primary prey items, California ground squirrels (*Spermophilus beecheyi*) and Botta's pocket gopher (*Thomomys bottae*), are often controlled using diaphacinone and chlorophacinone in agriculture. In developed areas, rodent pests are often poisoned with commercially available brodificoum. The slow action of these anticoagulants often assures that the target animal that consumes it has time to return to its burrow before succumbing to the toxin, thus minimizing the above-ground exposure of non-target predators and scavengers to the carcass. Badgers; however, primarily dig for their prey, and therefore may still be at a high risk of consuming poisoned rodents underground.

Our research occurred in the Bureau of Land Management's (BLM's) Fort Ord Public Lands in northern Monterey County, California (36.68° N 121.77° W; elevation 20-250 m), an area that encompasses 60 km^2 of grassland, coastal sage scrub, maritime chaparral, and coastal oak woodland habitats. Ten badgers, 4 males and 6 females, were captured between May 2005 and August 2006 using a stopped body snare set in burrow entrances. Trapped badgers were restrained with a handling pole and transferred first to a large canvas bag, then to open-topped, 55-gallon barrels for transport to a veterinary clinic. Blood samples were taken after badgers were anesthetized for surgical implantation of a radio transmitter weighing 85 g (model# IMP400/L, Telonics Inc., Mesa, AZ; details of surgical procedure in Quinn 2008). Badgers were first hand-injected with an intramuscular injection of tiletamine and zolazepam (Telazol®, Fort Dodge) administered at a dose of 3 mg/kg. When the animal was minimally responsive, general anesthesia was induced using a mask with a mixture of isoflurane and oxygen at 3% for induction and 1-2% for maintenance, delivered via a vaporizer. A 10 mL blood sample was taken via cephalic or jugular venipuncture using a 22-gauge needle, and placed in a serum separator tube. Samples were centrifuged, and the serum was separated from the cellular fraction by centrifugation then siphoned off into 2 mL cryovials and frozen at –80 C for later analysis.

Sera were tested for antibodies against canine distemper virus (CDV), canine parvovirus (CPV), *Leptospira interrogans* serovar *canicola, pomona, hardjo*, and *grippo*. Serologic tests were conducted at the Animal Health Diagnostic Center (College of Veterinary Medicine, Cornell University, Ithaca, New York 14852 USA). Antibodies to distemper virus were detected by serum neutralization (CDV-SN) tests.

Hemagglutination inhibition (HAI) was used to detect antibodies specific for canine parvovirus (CPV-2). Lyme disease serology testing was conducted by the Diagnostic Center for Population and Animal Health (Michigan State University, Lansing, Michigan, 48910, USA). *Leptospira sp.* serogroups and Lyme disease antibody titers were detected by rapid serologic assays known as microagglutination test (MAT). Indirect fluorescent antibody (IFA) used to confirm detection of *B. burgdorferi.*

Sera from nine badgers and one sample of the small intestine (ileum, duodenum and jejunum), large intestine (colon) and mesenteric lymph node were submitted for Johne's testing. Antibodies to *Mycobacterium paratuberculosis* were detected by using a protein G conjugate. No isolation of mycobacteria was made from the tissue samples using the Becton-Dickinson MGIT (Becton Dickinson Diagnostic Systems, Sparks, Maryland, 21152 USA) liquid culture system. The BACTEC MGIT (mycobacterial growth indicator tube) 960 system (Becton Dickinson Diagnostic Systems, Sparks, Maryland, 21152 USA), uses an oxygen-quenching fluorescent sensor in conjunction with software algorithms to determine when significant bacterial growth has occurred in the tubes. This system has been adapted for detection of *M. paratuberculosis* in veterinary clinical samples by using a new culture medium specific for *M. paratuberculosis*, called MGIT ParaTB medium (Becton Dickinson Diagnostic Systems, Sparks, Maryland, 21152 USA), and a modified algorithm built into the MGIT 960 instrument for interpretation of fluorescence measurements of each culture tube (Shin *et al.* 2007). Acid-fast testing and polymerase-chain reaction confirms the identity of mycobacterial isolates (Shin *et al.* 2007). Antibodies to *Toxoplasma gondii* (TOX) were detected using Toxotest-MT "Eiken" (Tanabe USA Inc., San Diego, California, 92111

USA). Latex particles coated with inactivated toxoplasma antigen form agglutinating patterns in the presence of specific antibodies in the serum. Serology to determine plague, *Yersinia pestis*, was tested for antibodies using the passive hemagglutination and inhibition tests. Test was selected based on the *Laboratory Manual of Plague Diagnostic Tests* (Population Health and Reproduction, School of Veterinary Medicine, University of California, Davis, California 95616 USA).

Additionally, sera samples were examined for the detection of anaplasmosis, *Anaplasma phagocytophilum*. Real-time polymerase chain reaction (RT-PCR) was used to detect *A. phagocytophilum* DNA (Drazenovich *et al.* 2006). This diagnostic test is both sensitive and specific for the acute phase diagnosis of anaplasmosis. Ticks removed from captured badgers were identified as *Dermacentor sp.* which has been identified to be vectors of anaplasmosis in the North America (Vectoborne Research Laboratory, School of Veterinary Medicine, University of California, Davis, California, 95616 USA).

We also obtained liver samples during routine necropsies of two animals that died during the course of the Monterey County study, and from one road-killed animal that was collected in Los Angeles County (one animal from the Monterey County study was found dead of unknown causes; the other died due to internal complications with the radio-transmitter [Quinn *et al. in prep*]). Liver samples were frozen in whirl-packs at –80 C until analysis. These liver samples and nine sera samples were submitted to the California Animal Health & Food Safety Laboratory (University of California, Davis, California 95616 USA) to determine the presence of anticoagulant rodenticides. Submitted samples were considered positive if they exceeded the method detection limit (lowest concentration detectable).

Additional tissue samples were placed in buffered 10 percent formalin, imbedded and mounted on slides for microscopic examination. Histology was performed at the Department of Pathology at School of Veterinary Medicine (Department of Pathology, School of Veterinary Medicine, University of California, Davis, California, 95616 USA).

Prevalence of antibodies to CDV was 70% for the 10 animals tested. Toxoplasma prevalence was 50%. One animal tested positive for anaplasma; the remaining nine tested negative, although three were weakly negative results. All animals tested negative for antibodies for Leptospira, Johne's disease, Lyme disease, Canine parvovirus, and plague. All serum samples tested negative for the presence of anticoagulants, as did the 2 liver samples from the animals in Monterey County. The liver sample of the animal from Los Angeles County contained trace amounts of brodificoum (Table A.1).

Table A.1: Results of serologic testing and anticoagulant screening of American badgers (*Taxidea taxus*) from Monterey County, California. Where ratio is indicated, it denotes the highest dilution at which the observed positive/negative was determined.

Animal ID	Sex	Age	Date trapped	Canine distemper	Toxoplasma gonii	Anticoagulant	Anaplasma	Date Deceased
1	Male	Adult	5/14/2005	Pos. 1:16	Neg.	Neg. (serum)	Neg.	N/A
2	Female	Adult	5/25/2005	Neg. 1:8	Pos. 1:256	Neg. (serum)	Neg. (weak)	4/2006
3	Female	Juvenile	5/25/2006	Pos. 1:8	Neg.	Neg. (serum)	Neg. (weak)	N/A
4	Female	Adult	6/15/2005	Pos. 1:8	Pos. 1:256	Neg. (serum)	Neg.	N/A
5	Female	Adult	6/24/2005	Pos. 1:12	Neg.	Neg. (liver)	Neg. (weak)	9/6/2006
6	Male	Juvenile	8/18/2005	Neg. 1:8	Pos. 1:1024	Neg. (serum)	Neg.	N/A
7	Male	Adult	8/22/2005	Pos. 1:8	Pos. 1:512	Neg. (serum)	Pos.	N/A
8	Female	Juvenile	10/25/2005	Pos. 1:8	Neg.	Neg. (serum)	Neg.	N/A
9	Female	Juvenile	11/5/2005	Pos. 1:8	Pos. 1:2048	Neg. (liver)	Neg.	4/18/2006
10	Male	Adult	5/30/2006	Neg	pending	Neg. (serum)	Neg.	N/A

Because none of these tests have been validated in badgers, these results should be interpreted with caution. The higher titers for Toxoplasma suggest exposure, which is not surprising given the life cycle of the parasite, as well as the environmental resistance of sporocysts. Because of adjacent residential developments, feral cats (*Felis catus*), a definitive host of Toxoplasma, are common around the edges of the Fort Ord Public Lands. Badgers are almost exclusively carnivorous, and on the central coast of California, primarily subsist on gophers (*Thomomys bottae*), meadow voles (*Microtus californicus*) and California ground squirrels (*Spermophillus beecheyi*), and will also take ground-nesting birds (Quinn 2008); these are all intermediate hosts. Exposure to Toxoplasma usually results in infection, since many mammals are persistently infected with tissue cysts (Riemann *et al.* 1978). However, terrestrial mammals that have been exposed to Toxoplasma over their evoluntary history are often host-adapted to survive, or fail to exhibit, the symptoms of infection (Frankel 1989). From our brief physical exam, the badgers in this study did not appear to be symptomatic for the neurological effects of Toxoplasma, and most went on to live up to at least 600 days after capture. However, the one animal that had the extremely high titer of 1:2048 was found dead 4 months after her release. The extreme autolysis of her carcass was such that we were unable to determine the cause of her death; however, the possibility that she succumbed to Toxoplasmosis can not be ruled out. While the CDV results suggest past exposure for several animals, because this test has not been validated these weak positives might be considered indeterminate or inconclusive results. Further, we did not observe the symptoms of CDV in the badgers we captured.

Antibodies for most of the diseases tested here were not detected. However, as all badgers live-trapped for this study appeared healthy upon their capture and release, we expected that pathogen exposure to highly pathogenic diseases would be low. Our goal was instead to establish baseline data for the exposure of badgers to disease in California. The common or excessive exposure of apparently healthy animals to disease often warrants further investigation into the identification and pathology of specific diseases, perhaps through the dedicated search for infected animals and carcasses. Although we failed to detect such levels of exposure here, our sample size was extremely small. More data are needed—and optimally on a larger geographical scale as well—to effectively address the overall health of badger populations statewide.

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APPENDIX B

MORTALITY RELATED TO AN IMPLANTED ABDOMINAL RADIO TRANSMITTER IN AN AMERICAN BADGER (*TAXIDEA TAXUS*)

J. H. Quinn, C. Kreuder-Johnson, P. Gaffney, D. Jessup, M. Murray, and K. Gilardi.

INTRODUCTION

The development of abdominally-implanted radio transmitters has made possible the radio telemetry studies of many species that are precluded from wearing a standard radio collar. Species whose neck circumference is almost equal to or greater than that of their head tend to shed collars (Melquist & Hornocker 1979, Hoover 1984, Jessup & Koch 1984). Burrowing mammals that need to maneuver through burrows equal in size to their body may be obstructed by collar-mounted transmitters. In these species, the cost and labor associated with abdominal implant surgery can be outweighed by the benefit of the longevity of an abdominal implant compared to a radio collar (Smith & Whitney 1977).

Transmitter implants are mechanically similar to collar-mounted transmitters, but are coated with wax, making the material exposed to the bodies immune system biologically inert. Although many evaluations of implanted transmitters report no effect on the movement, reproductive potential, or survival of the implanted animal (Reid *et al.* 1986, Van Vuren 1989, Klugman & Fuller 1990); there are reports of adverse outcomes of the implant procedure. Reported complications include dehisces of the surgical site (Minta 1990, Paulson 2007), circulatory failure following surgery (Ranheim *et al.* 2004), and adhesion of the implant to the omentum (Guynn *et al.* 1987, Ågren *et al.* 2000). In some of these cases, the complications resulted in mortality of the implanted animal (Minta 1990, Ranheim *et al.* 2004, Guynn *et al.* 1987, Paulson 2007).

American badgers (*Taxidea taxus*) have loose skin, wide neck circumference compared to their head, and a primarily fossorial lifestyle, all of which increase their tendency to shed even harness-style radio collars (Messick & Hornocker 1981, D. Collins *pers. comm.*, J. Duquette *pers. comm.*). Badgers have been implanted with radio transmitters in several studies (Minta 1993, Hoff 1998, Goodrich & Buskirk 1998, Newhouse & Kinley 2000, Hoodicoff 2003). Two have reported mortality due to dehisces of the surgical site (Minta 1990, Paulson 2007), but none have reported mortality due to internal complications. Here, we describe the mortality of an American badger one year following radio transmitter implantation due to omental adhesions and torsions, followed by omental abscessation and sepsis.

Methods

Research occurred in the Bureau of Land Management's (BLM's) Fort Ord Public Lands in northern Monterey County, California (36.68° N 121.77° W; elevation 20-250 m). Ten badgers were trapped and implanted with radio transmitters for a study investigating badger spatial behavior and habitat preferences (Quinn 2007). Badger 370, an adult female weighing 6.9 kg, was captured at 0545h on 24 June 2005. She was captured with a stopped body snare set in her burrow entrance. The badger was first restrained with a handling pole for removal from the snare, and was transferred first to a large canvas bag, then to an open-topped, 55-gallon barrel for transport to a veterinary clinic. At the clinic, the badger was placed back in the canvas bag and manually restrained, and a hand-injected intramuscular injection of tiletamine and zolazepam (Telazol®, Fort Dodge) was administered at a dose of 3 mg/kg. The badger was removed from the bag once she was recumbent and minimally responsive. She was then placed in ventral recumbency on a surgical table. General anesthesia was induced using a mask with a mixture of isoflurane and oxygen at 3% for induction and 1-2% for maintenance, delivered via a vaporizer.

The badger was intubated with an endotracheal tube to ensure a clear airway during surgery. Measurements, hair and blood (10 ml) samples were taken at this time. The animal was also subcutaneously implanted with uniquely numbered PIT tag between the shoulder blades. Body temperature, heart rate, respiratory rate, and oxygen saturation (using a pulse oximeter applied to the animal's tongue) was monitored and recorded during the entire anesthetic period approximately every 5 minutes. No abnormalities were observed.

A veterinarian surgically implanted the badger with a Telonics IMP400/L intraperitoneal transmitter weighing 85 g (Telonics, Inc., Mesa, AZ). The transmitter was was-coated and cylindrical in shape, measuring 10 cm in length and 4 cm in diameter. The animal was placed in dorsal recumbency and a routine surgical preparation of the ventral midline was performed following shaving of skin. Surgical preparation was limited to a 3 cm by 5 cm area to minimize heat loss after release. A skin incision was made caudal to the umbilical scar. Subcutaneous tissue was bluntly dissected and the incision continued through the linea alba. The radiotransmitter implant was inserted freely into the lower right quadrant of the abdominal cavity. The surgical incision was closed with 3-0 absorbable suture material using a combination of continuous and the cruciate suture pattern in four layers (linea alba, subcutaneous fat layer, subcuticular skin layer, and skin layer). Enrofloxin (Baytril™, Bayer HealthCare, Research Triangle Park, North Carolina) at a dosage of 7.5 mg/kg, benzyl penicillin at a dosage of 40,000 IU/kg, and carprofen (Rimadyl™, Pfizer, New York, New York) at a dosage of 2.2 mg/kg were injected subcutaneously intra-operatively to relieve pain, minimize swelling, and to prevent infection. The animal was then extubated and monitored for recovery from anesthesia and post-operative complications in the transport carrier with added bedding. Post-operative monitoring of respiratory rate, activity, surgical incision discharge, and self-induced trauma to the surgical site every five minutes suggested a normal recovery. The badger was then transported back to the burrow capture site for release once she was alert and fully recovered from anesthesia (at 0600h on 25 June 2007). She was checked once daily via radiotelemetry during the first 48 hours post-surgery placement and was observed to be mobile and actively foraging. Thereafter, the badger was located on average once weekly via radio telemetry.

The badger exhibited normal activity and movement behavior for the following 433 days she was tracked. Her home range size was approximately 2 km^2, similar to other females in the study (Quinn 2008). Between 28 August and 4 September, her normal radio signal was detected nightly from the same general area (within about 100 km^2); however, her exact location was not determined. On 5 September 2006, a mortality signal was received from the same general area at 2235h. The following morning, the signal was tracked to a burrow. The burrow was excavated and the carcass retrieved by 1200h. The carcass was wrapped in plastic and placed on ice in a cooler, and was immediately transported to the UC Davis Veterinary Medicine Teaching Hospital. The carcass was then refrigerated at 4° C for approximately 20 hours. A full necropsy was performed.

Results

On gross examination, the carcass was moderately autolyzed. The badger weighed 4.55 kg and had minimal subcutaneous, perirenal and pericardial adipose tissue. In the left cranial quadrant of the abdomen, the radio transmitter completely encircled by greater omentum. The omentum was tightly adhered to the surface of the transmitter. Within the greater omentum, proximal to the transmitter (toward the stomach), there was a large, firm 10 x 8 x 5 cm abscess with a vascular capsular surface mottled dark red, pink and tan, a varibly thick wall, and a central cavity filled with inspissated pus. Between the transmitter and the abscess, there was a 360-degree omental torsion. Between the abscess and the greater curvature of the stomach, there was a 720-degree omental torsion. The vasculature of the omentum overlying the abscess and the radiotranmitter was diffusely congested. Multifocally throughout the parenchyma of the liver, spleen and renal cortices, there were innumerable, often coalescing, circular regions of pallor, that ranged in size from 0.1 to 0.7 cm in diameter.

On microscopic examination, there was acute, suppurative and necrotizing, embolic hepatitis, splenitis and nephritis. There was chronic peritonitis with mesothelial hyperplasia and abundant colonies of bacterial cocci within the abscess and peritoneum. There was severe regionally extensive pulmonary edema and subacute, lymphoplasmacytic perivascular encephalitis. There was active folliculogenesis in the ovaries.

Culture of the lungs, liver and the abscess all grew very small to large numbers of Beta-hemolytic streptococcus, as well as small numbers of additional organisms which varied by organ. Culture of the feces was positive for *Salmonella arizonae*. The remainder of the gross and histologic examination was hindered by autolysis.

Discussion

The cause of death in this American badger is believed to be multiorgan failure from sepsis secondary to a transmitter associated omental torsion. The most likely scenario is that, for reasons unknown, over a year following implantation, there was a torsion of the omentum proximal to the transmitter. The torsion likely led to compromise of omental blood supply, bacterial colonization and abscessation. Bacteria from the abscess then seeded the blood, resulting in bacterial showering of multiple organs with subsequent inflammation, necrosis and organ failure. Poor body condition and loss of 34.06% of body weight since the time of implantation suggests there was chronic weight loss; perhaps associated with the chronic abscess, and/or with normal seasonal weight loss (Harlow 1977).

Adhesion of an implanted radio transmitter to the omentum has been described in beavers (*Castor canadensis*); 2 of 10 animals necropsied exhibited omental adhesions (Guynn *et al.* 1987). These did not result in torsion or death; however, the adhesion of a transmitter to the intestinal wall of the ileum in a third animal did fatally obstruct the lumen. Likewise, Ågren *et al.* (2000) observed omental adhesions in 2 of 3 implanted European badgers (*Meles meles*). During the 3 months that the transmitters were in place, no torsions or mortality occurred as a result of the adhesions. Encapsulation of a transmitter in a fisher (*Martes martes*) has also been observed, with no apparent adverse effects on the animal (R. Weir *pers. comm.*).

To our knowledge, this is the first reported radio transmitter associated mortality of this kind in American badgers. Of the nine other badgers implanted for this study, two others died. Only fur and bones were recovered from one of these animals, and the other was necropsied. The likely cause of death in that badger was trauma; however, no intact viscera were available to evaluate due to advanced autolysis. In another study of American badgers, no adhesions were observed in post-mortem examination of 14 implanted animals (T. Kinley *pers. comm.*). Still another study involving 7 necropsied badgers noted 1 adhesion, perhaps due to a small scratch in the wax coating of the transmitter. In this case, the transmitter had subsequently detached from the abdominal wall and returned to a free-floating state (R. Weir *pers. comm.*).

Alternatives to implant transmitters do exist for badgers. Harness-mounted radio transmitters that strap behind the front legs as well as around the neck have been used in several studies with mixed results. In several cases, the animals still managed to slip out of the harness; at times inexplicably (Collins 2003, J. Duquette *pers. comm.*), and trap-wary badgers can be difficult to recapture (Paulson 2007). If harnesses are fit too snuggly (to prevent slippage), abrasions can occur (J. Duquette *pers. comm.*). Properly fit harnesses can stay in place for many months, and may be streamlined enough not to interfere with the animals' movements. However, they may require periodic monitoring in order to adjust for seasonal fluctuations in the badgers' weight (D. Collins *pers. comm.*, J. Duquette *pers. comm.*).

While there appears to be some risk associated with the adhesion of abdominally-implanted radio transmitters in badgers, the magnitude of the risk may be small (of 22 animals, 2 adhesions and one adhesion-related mortality; a 4.5% mortality rate). This risk could potentially be further reduced by attaching the transmitter to the peritoneal wall (Minta 1990, Ågren *et al.* 2000), by folding it into the omentum (Guynn *et al.* 1987), or by assuring the surface of the transmitter is free of scratches or irregularities.

Monitoring for unusual reduction in activity of implanted animals may also alert researchers to the presence of a problem; however, the badger observed in this study remained active until her death. Moreover, even healthy badgers do spend multiple nights in one location, primarily in the winter but occasionally during other seasons as well (Sargeant & Warner 1972, Lindzey 1978, Hoodicoff 2003, Collins 2003, Quinn & Diamond *in prep*). If this small level of risk associated with adhesion (when combined with other risks related to surgical procedures) cannot be tolerated, harness-mounted transmitters provide another viable option. Although mortalities related to harness use have not been documented, the additional cost of multiple captures and sedations, and potential loss of data due to shed harnesses should still be considered.

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APPENDIX C

A COMPARISON OF MONITORING METHODS FOR AMERICAN BADGERS (*TAXIDEA TAXUS*)

J.H. Quinn and T. Fullman

In the Fort Ord study site, we placed 15 survey stations within the area encompassed by the home ranges of eight of the radio-marked badgers. A 1 km^2 grid of ten cells was mapped across the study area, and a station was placed at a random location within each grid cell. Each survey station consisted of one camera trap and one scent circle spaced 50 meters apart. Both the camera and scent circle were baited with Canine Call scent lure, and were checked daily (in the morning) for ten days. For each station check, number and species identification of tracks were recorded for scent circles, then scent circles were smoothed and camera film was replaced as necessary. At the end of the survey period, camera film was developed, and species photographed each day at each station were recorded. Spotlight surveys were conducted along main roads in the study area, beginning two hours after sunset. For four nights, observers drove the same established routes, and recorded the number, location and identification of animals seen from the vehicle. Routes crossed through the ranges of eight of the study animals. Burrow searches were conducted along 15 1-km-long transects placed throughout the home range areas of 8 of the radio-marked animals. The beginning of the transect was located randomly at one corner of the grid cell, and was then walked on a random bearing within the 90 degree angle facing into the grid cell. Number, location and age of burrows encountered along each transect were recorded.

A detection index was calculated for each survey method: the number of badger detections per station per day for camera and scent stations; and the number of badger detections per linear kilometer per day for spotlight and burrow transects. The number of tracking/camera stations, and linear kilometer of spotlight/burrow transects occurring in each radio-marked animal's home range was recorded; and a detection index for each home range was calculated. We also calculated the probability of obtaining the same number of detections as badgers in the area (number of stations with detection/number of home ranges covered). Finally, we calculated the probability of detecting one animal in its home range by dividing the home range detection index by the number of stations or transects within that home range. We compared the detection indices and probabilities between each method.

Spotlight surveys failed to detect badgers (0 detections/km/night) as did camera station surveys (0 detections/station/day). The detection index for scent stations was extremely low, as only one positive detection was recorded, resulting in a detection index of 0.007 detections/station/night for that method. The scent station that recorded one badger track was one of two stations located in one badger's home range. Thus, for scent stations, the probability of detecting that animal within its home range was 2.5%. New badger sign was detected on 12 of the 15 1-km transects, while old badger sign was detected on all transects. If transects were considered independent, we would have estimated 12 to 15 badgers being present in the area. Transect searches resulted in overall detection indices of 1.6 detections/km for new sleeping dens, and 4.3 detections/km for new hunting holes. Using the coarser index of a positive (1) or negative (0) detection for each transect rather than numbers of digs, detection indices would be 0.93 detections/km for new activity and 1 detection/km for old activity. Given the home range sizes of the animals in this study, the probability of detecting animals within their home ranges using the transect method was 1; in fact, to have a detection probability less than 1, an animal would have to have less than 1 kilometer of transect within its home range. This did not occur with any of the animals using this design.

APPENDIX D

CONSIDERATION AND COVERAGE FOR AMERICAN BADGERS (*TAXIDEA TAXUS)* IN CURRENT (2007) VERSIONS OF REGIONAL CONSERVATION PLANS IN CALIFORNIA.

Consideration and coverage for American badgers in current (2007) versions of regional conservation plans in California. Plan type acronyms: HCP- Habitat Conservation Plan, NCCP- Natural Community Conservation Plan, MSCP- Multiple Species Conservation Plan, MSHCP- Multiple Species/Habitat Conservation Plan. Notes: SAC- Scientific Advisory Committee.

County/ region	Type of plan	Badger occurrences recorded*	Badger considered?	Badger covered?	Habitat covered?	Notes
Butte	HCP/NCCP	Historic	No	No	Yes	
Coachella	MSHCP	Yes	No	No	Yes	
East Contra Costa	HCP	Yes	No	No	Yes	
Imperial Irrigation District	NCCP	Yes	No	No	No	
Mendocino	HCP/NCCP	Yes	No	No	Yes	
Orange Co. Central Coastal Subregional Plan	NCCP	Yes				
Placer Co.	NCCP	Yes	n/a	n/a	Yes	plan in early development
Western Riverside Co.	MSHCP	Yes	Yes	Yes	Yes	
San Diego	MSCP	Yes	Yes	Yes	Yes	
Santa Clara Co.	HCP/NCCP	Yes	Yes	No	Yes	
Yolo Co.	HCP/NCCP	Yes	Yes	n/a	Yes	plan in development, consideration recommended by SAC
Yuba/Sutter	HCP/NCCP	No	Yes	n/a	Yes	plan in development, consideration recommended by SAC
North Co. San Diego	MHCP	Yes	No	No	Yes	

* For this report